MARKET FEASIBILITY AND PRACTICABILITY ASSESSMENT OF RUBBERISED BITUMEN FOR SRI LANKAN ROAD PAVEMENTS

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ABSTRACT

Conventional Bitumen (CB) has limitations in Sri Lankan context due to its tropical climate, as CB's low stiffness modulus, low softening point, low viscosity, high temperature susceptibility and poor cohesion properties are aggravated in this environment. This leads to cracks on the road surfaces, which subsequently leads to surface failure because of frequent heavy rains in the region. Therefore, to avoid the adverse properties of CB, the technical feasibility of modifying bitumen with natural rubber and crumb rubber has been studied recently. However, the question remains whether these options are economically feasible in the Sri Lankan context.

This paper presents a study which was carried out focusing the above issue. The study was carried out based on a preliminary literature review on the use of Natural Rubber Modified Bitumen (NRMB) and Crumb Rubber Modified Bitumen (CRMB) to identify technical feasibility and impacts, and an expert opinion survey with academic and industrial experts in the Highway field to identify the impacts.

These impacts were identified in three categories, i.e. Economic, Social and Environmental. Comparing the economic impacts and lifecycle cost aspects it was concluded that NRMB and CRMB are more economically feasible over CB. Moreover, during the study NRMB and CRMB were found to be more environmentally and socially feasible as well. CRMB further provides additional benefits as it uses recycled rubber, which in turn reduces environmental and social issues created by waste tyres. Furthermore, CRMB has a lower cost of modification compared to the NRMB. Owing to these aspects and the prevailing market situation, it was concluded that CRMB is more appropriate to Sri Lanka.

Keywords: *Conventional Bitumen; Crumb Rubber Modified Bitumen; Economical Feasibility; Natural Rubber Modified Bitumen.*

1. INTRODUCTION

An appropriate transportation system is of utmost importance to a healthy national economy, in which roadways are an integral part. Therefore, as Glover (2007) stated, construction and maintenance of long lasting road pavements will have a significant impact on the economic vitality of a nation. Further, according to Glover (2007), the main reasons for the deterioration of road conditions include the overall increase of traffic, poor quality of asphalt binder and weathering effects of climatic changes. Nevertheless, road pavement bitumen is thermoplastic, visco-elastic adhesives. In dense asphalt concrete, the binder is only about 5% but it plays very significant role in the overall properties of the composite material. The binder strongly affects both the load spreading capability and resistance to distortion under heavy traffic (Fernando, 2006).

The physical, mechanical, and rheological behaviour of bitumen in road and building construction is governed by its structure and chemical composition (Rahman, 2004). Asphalt can be classified by its chemical composition and physical properties. The pavement industry typically relies on physical properties of asphalt for the characterisation of performance, although the physical properties of bituminous binders are a direct result of its chemical composition (Glover, 2007). In fact, above information can be used to select, mix and/or modify asphalts to obtain binders that will perform in a cost-effective manner (Forbes *et al*., 2001). Currently there are various types of modifiers, capable of improving the performance of bitumen binders (Fernando, 2006). Fernando (2006) has discovered a modifier should have properties like; readily availability, improves some or most of the properties of bitumen, easily processed by conventional equipment, and cost effectiveness.

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Considering the rubber form of modifications for bitumen, there are highly available natural rubber (Form of latex or powder), Synthetic rubber, Vulcanized rubber (waste tires) and buffing dust from retreading tire industry to do the modification in Sri Lanka. According to the Bandini (2011) when crumb rubber is blended with bitumen at high temperatures (wet process) to produce a modified binder, the two materials interact once the bitumen components migrate into the rubber causing it to swell. Initially, the bitumen-rubber interaction is a non-chemical reaction, where the rubber particles are swollen by the absorption of the aromatic oils of bitumen. The impact of the CR modification improves the aging susceptibility, decreasing the binder aging ratio (Martinez *et al*., 2006). Moreover, NR is a fine organic polymer, because it is chemically very compatible with bitumen very effective and economical. The persistence elastic response of rubberised bitumen is primarily due to the entanglement of the flexible long chain rubber molecule together with some chemical reactions (Fernando, 2006).

In Sri Lankan context CB gain heavy economic losses due to a life of conventional road surfaces are minimised under hot climates and heavy axle loads and the cost of maintenance of the roads (Fernando, 2006). Thus, discovering the applicability and financial feasibility of Rubberised bitumen as an alternative modifier for CB for road construction in Sri Lanka is a timely requisite.

2. LITERATURE FINDINGS

2.1. PAVEMENT DISTRESSES AGAINST CONVENTIONAL BITUMEN IN SRI LANKAN ROAD PAVEMENT

Out of the approximately 30,000 km of paved roadways in Sri Lanka (RDA, 2007). Harischandra (2004), identified several types of road defects as the most visible defects in conventional bitumen penetration macadam roads, viz. road deformations, cracks, surface texture deficiencies, edge defects, potholes. The possible road deterioration causes for these defects were identified by the authors as; aging and weathering, environment (temperature, moisture), drainage and traffic.

Cracks are fissures resulting from partial or complete fractures of the pavement surface. According to Harischandra (2004), who illustrated reasons for cracks as; loss of waterproofing of pavement layers, loss of load spreading ability of the cracked material, pumping and loss of fines from the base course and loss of riding quality through loss of surfacing. In addition cracks of asphalt pavements are cracking that is associated with the development of thermal stress, usually manifesting itself as transverse and block cracking (Association of Asphalt Paving Technology, 2011).

Edge defects also have considerable importance in asphalt surfaces. These defects occur along the interface of a bituminous surface pavement and shoulder where the shoulder is unsealed (Western Bay of Plenty District Council, 2013). Furthermore, Harischandra (2004), illustrated edge defects frequently happen on one side of the roadway or tire wear and attrition.

2.2. INVOLVEMENT OF BITUMEN FOR ROAD DISTRESSES

Road pavement performance properties are mainly affected by the bitumen binder properties. It is well known that the rheological properties and durability of conventional bitumen are not sufficient to resist pavement distresses (Ali *et al*., 2013). According to Fernando (1998), who identified that properly designed roads with standard construction practices and good quality aggregate, most of the surface problems could be traced to the inadequacy of the quality of bitumen. According to the author, several road pavement distresses are directly related to bitumen properties. A list of road problems along with the associated properties of the binder is given in Table 1.

Table 1: Binder Properties in Road Problems

Road Distress Modes	Associative Properties of Binder
Rutting and Distortion	Low stiffness modulus, low viscosity, low softening point, high temperature susceptibility, poor cohesion.
Bleeding	Low stiffness modulus, low viscosity, low softening point, high temperature susceptibility.
Stripping	Poor adhesion, low resistance to water, poor cohesion.
Ravelling, Fretting	Poor cohesion, poor durability.
Brittle Fracture, Thermal Cracking	High stiffness modulus, higher temperature susceptibility, low ductility, low tensile strength, low flexibility, poor durability.

Source: Fernando (1998)

According to the Table 1, Fernando (1998) realised that to resist the road pavement from rutting and distortion binder properties with high stiffness modulus, high viscosity, high softening point, low temperature susceptibility and better cohesion required. Hence, most of the road problems could be minimized or virtually eliminated if a suitable modified binder to improve the above properties. However, conventional bitumen is unable to improve these properties any further (Ali *et al*., 2013).

2.3. MODIFIED BITUMEN

Asphalt modification using additives dates back to the last century (King *et al*., 1999). As well as the patents for using modified asphalt dates back to 1823 (Isacsson and Lu, 1995). The conventional bitumen have a range of theological and durability properties that are not sufficient for resistance on distresses caused by the increase in traffic and total loading on current roadways.

By specialised refining practices, chemical reaction, and/ or additives, it has been found out that conventional bitumen can be modified to improve the contribution of asphalt binders to the resistance of asphalt mixtures to various pavement distress (Lee and Kamyar, 2006). Furthermore, modified bitumen is formulated with additives to improve their service performance by changing such properties as their durability, resistance to ageing, elasticity and or plasticity (BP Bitumen Australia, 2013). Kim (2009) illustrated that a modifier can be selected to improve one or more of the main performance related properties of asphalt. Also different modifiers that affect different properties can be combined to improve several properties. Ideally, a modifier will change rheological properties to match requirements as defined by resistance to pavement distresses as shown in the Figure 1.

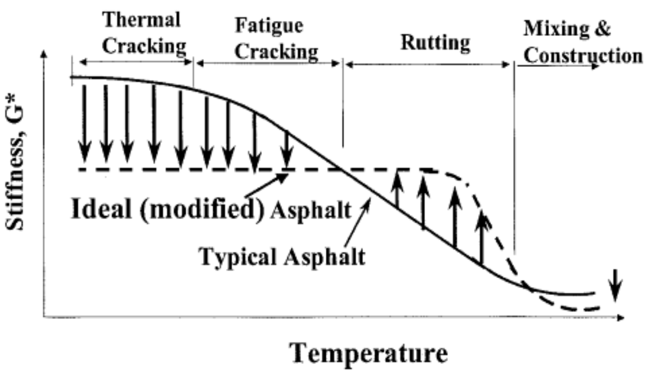

Figure 1: Schematics Shown the Target Change in Rheological and Failure Properties Expected
Source: Kim (2009)

Moreover, the Figure 1 can be used to realise that, several properties should be changed in bitumen modification to see an improvement in its performance (Fernando, 1998). They are; lower stiffness modulus at low service temperature to avoid thermal cracking, higher stiffness modulus at high service temperature to impact high thermal stability and hence to reduce rutting, permanent deformation and bleeding, lower stiffness modulus at compaction temperature and mixing temperature to improve workability at normal working temperatures, low temperature susceptibility, improved durability and cost effectiveness.

There are currently a large number of modifiers used for paving grade asphalts. From which, Kim (2009) showed that, Styrene Butadiene Styrene, Styrene Butadiene, Natural Rubber Latex and Crumb Rubber (Tire Rubber) are most commonly used in road industry.

Furthermore, most of the researchers believed that, the natural rubber and crumb rubber are adequate to use as modifiers for conventional bitumen. Hence the research finding is based on to find out the practicability side of these modifiers under Sri Lankan context.

3. RESEARCH METHODOLOGY

To achieve the study aims, qualitative comparative analysing approach was selected as the most suitable research approach. After the initial comprehensive literature survey undertaken to identify the technical feasibility of the natural rubber modified bitumen and crumb rubber modified bitumen, based on the data collected from industry and experts, the analysis was carried out to identify which modification is mostly suitable in the Sri Lankan context.

Semi-structured interviews were used in an expert opinion survey in this study to identify the market feasibility and practicability of bitumen modification with natural rubber and crumb rubber. Selected sampling was carried out to determine the interviewed experts, from industrialists, professionals and researchers in areas of natural rubber, crumb rubber, tyre and waste tyre. The initial interviews were carried out to determine the economic feasibility of deploying widespread use of natural rubber and crumb rubber asphalt. The following interviews were focused on the technical and practical implications it may have, and finally focusing on the marketability and environmental merits and demerits.

4. RESEARCH FINDINGS

Roads and transportation systems are considered as the arteries of economic development in a country and presently, road construction is vastly increased in the past few years (RDA, 2007). Ergo, Sri Lankan Government proceeds lots of road construction projects (e.g. like highways, road ways) on various places in Sri Lanka. However, according to experts' opinion, Sri Lanka still has not done any modification in the bitumen mixture that is being used in these development measures. According to them, Sri Lanka is still heavily reliant on the conventional type of bitumen, which only lasts about 15 years.

The research findings, based on the experts' opinions are presented henceforth on three parameters which are highly impacted with bitumen modification with natural rubber and crumb rubber. The parameters are identified as economic, environmental and social factors, as illustrated in Figure 2.

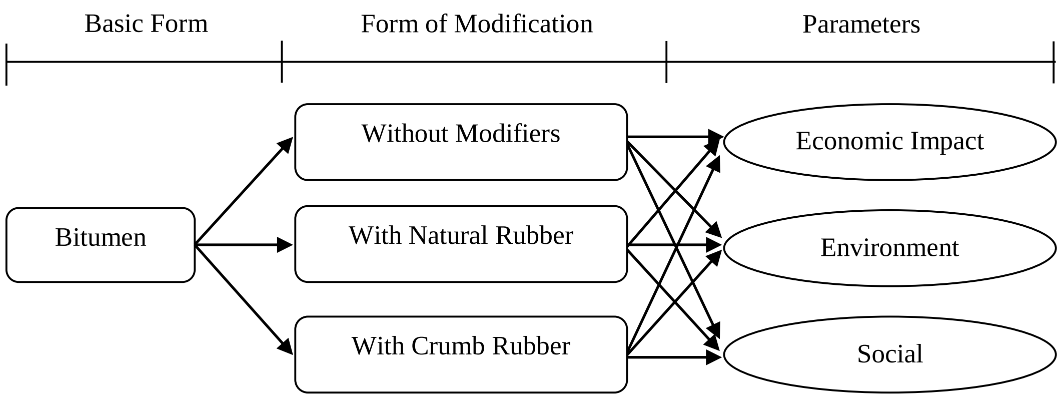

Figure 2: Form of Modifications and their Behaviours against Considered Parameters

4.1. ECONOMIC IMPACTS

The economic impacts suggested by the experts were based on the rationale that improvements to transportation networks, especially those in growing areas; tend to have impacts on local land markets. In principle, an improvement to a link in the network will confer economic benefits to adjacent and nearby properties. This study considered the initial cost of road construction (cost per km), cost of asphalt concrete (cost per km), cost of maintenance (cost per km) and life time of the design road separately for conventional bitumen pavement, natural rubber modified bitumen pavement and crumb rubber modified bitumen pavement. Table 2 shows a comparison between CB, NRMB and CRMB with relation to economic factors, as identified during the observations of the research.

Table 2: Economic Impacts

Parameter		Bitumen Modification		
		Conventional Bitumen	**NRMB**	**CRMB**
Economic	Cost of modification (Rs/Kg)	92.00	141.74	105.75
	Life span of the Road	15 - 20 Years	35 - 40 Years	35 - 40 Years
	Initial cost of Road Construction (LKR) per Km (X)	42,388,750.00	X > 42,388,750.00	X > 42,388,750.00
	Cost of asphalt concrete required to lay per Km (LKR) (Y)	14,093,750.00	Y > 14,093,750.00	Y > 14,093,750.00
	Cost of maintenance per month (Z)	250,000.00	Z < 250,000.00	Z < 250,000.00
	Government contribution for road construction	High amount of money have been allocated from the budget yearly for road rehabilitation and maintenance works	Comparatively less amount	Comparatively less amount

Results of the semi structured interviews showed that, bitumen modification with natural rubber and crumb rubber improves the service life and pavement performance also. Experts believe that, these modifications will increase the initial cost of roads and life span of a road. However, it was unanimously found that these modifications reduce the cost of maintenance of the pavements. The results of the market survey provided the required data to build a rate for each modification based on the cost needed to make 1 kg of modified bitumen. Hence, it is apparent that comparatively modified bitumen applications pose additional economic benefits over conventional bitumen apart from the increased initial cost.

4.2. ENVIRONMENT IMPACTS

Roads impact on the environment in many different ways, from the initial construction, maintenance, upgrading and usage of roads. Roads that impede drainage or cause run-off to be concentrated or polluted, can seriously degrade the environment. Furthermore, vehicles travelling on roads add to ambient noise and reduce air quality, which has the potential to affect people’s health.

However, this study only discussed the environmental impacts due to road construction with CB, NRMB and CRMB pavements as established from the expert survey, i.e. reduction of natural resources, emission of gases, and noise intention to environment. Table 3 provides a summarised comparison of these environment impacts between CB, NRMB and CRMB.

Although, NRMB and CRMB provides additional impacts to the environment which are not mentioned in the Table 3, including, the possibility of increasing rubber cultivation in Sri Lanka. The study results showed that 15% of new constant demand for natural rubber will be added while establishing a NRMB production in the country, which will increase the current demand for rubber from estates. On the other hand, unusable tires are waste pilling up impacting the environment. The quantity of waste tire that is being trashed to the environment can be reduced by establishing CRMB production in Sri Lanka.

Table 3: Environment Impacts

Parameter		Bitumen Modification		
		Conventional Bitumen	**NRMB**	**CRMB**
Environment	Reduction of natural resources	Crude oil - 2,875,000.00 MT/Year Stone - 665,500.00 MT/Year	Comparatively less amount due to replacement of bituminous material	Comparatively less amount as virgin material is replaced by recycled material
	Emission of gases due to refinery and asphalt concrete manufacturing process	Accumulate high consistence of Sulphur Oxides, Carbon Monoxide, Vapours of Hydro carbons, Aldehydes and Ammonia.	Comparatively less amount	Comparatively less amount
	Level of noise intention during operational stage	60 - 70 dB	Approximately 30 - 40 dB	Approximately 30 - 40 dB

4.3. SOCIAL IMPACTS

Social impact are identified as significant potential positive and negative changes in peoples' cultural traditions and lifestyles, their physical and psychological health, their families, their institutions and their community. Out of the myriad of social impacts road construction poses, a handful was identified more prominent in this study based on expert opinions. Table 4 gives a comparison between these social factors as identified from the semi structured interviews.

Table 4: Social Impacts

Parameter		Bitumen Modification		
		Conventional Bitumen	**NRMB**	**CRMB**
Social	Unit cost to the vehicle operators	Unit cost to the vehicle (Rs/Km) Car- 5.3, two-wheeler - 1.33, truck - 12.14, bus - 11.32, LCV - 12.26.	Unit cost to the vehicle (Rs/Km) Car- 4.82, two-wheeler - 1.23, truck - 11.93, bus - 10.97, LCV - 12.07.	Currently under research
	Possibility of occurring road accidents	Having high possibility	Comparatively low possibility	Comparatively low possibility
	Travel time saving cost	Having considerable amount	Comparatively less amount	Comparatively less amount
	Level of disturbance people are facing while driving vehicle	Having considerable amount	Comparatively less amount	Comparatively less amount
	New demand for modifiers	-	8.05 Billion	1.38 Billion
	Benefits to the people	-	High demand for rubber states, labour salaries will increase	Waste tire converts to money and reduce hazards of dengue and air pollution

Table 4 shows that, the social impacts focused in this study were generally unit cost to the vehicle operator, possibility of road accident and travel time saving cost to people that has social impacts in CB, NRMB and CRMB road pavements. Additionally, productions of NRMB and CRMB provide more benefits to the society; i.e. having a big demand (Rs.8.05 billion) for natural rubber provide a protection to the rubber industry. When the industry is making profits, automatically these profits are distributed among the communities who are involved with the industry, which improves their quality of life. Moreover, CRMB production also provides opportunity to society to make money by selling unusable tire to the crumb rubber manufacturers. According to statistical data on waste tyres it makes Rs.1.38 billion from the sale of waste material.

5. CONCLUSIONS

The study focuses on the technical feasibility, economic, social and environmental impacts of Conventional Bitumen (CB), Natural Rubber Modified Bitumen (NRMB) and Crumb Rubber Modified Bitumen (CRMB). As per the literature section, it is apparent that all three bitumen types; CB, NRMB, and CRMB are technically feasible and provides reasonable performance in the pavement performance criteria in the Sri Lankan context.

The research findings were mainly aimed to discuss the impacts of various bitumen types. These impacts were identified mainly in three categories; Economic, Social and Environmental. Comparing the economic impacts, it can be concluded that NRMB and CRMB are more economically feasible over the CB. This is mainly due to the increase of life span decrease of maintenance of the pavement. NRMB and CRMB have a life span more than twice that of the CB. (CB has a life span of 15 year whereas other methods have a life span of 40 years.) This fact dominates over the increased initial cost of NRMB and CRMB about 10% - 12% of the CB.

However, overall life cycle cost of the pavement; has not been considered in this study due to the lack of information on this area in Sri Lankan context. These figures and a lifecycle cost data has to be taken into consideration by policy makers and development authorities to promote durable sustainable materials in our national development agendas.

The environmental impacts relating to these three methods are the mainly, loss of natural resources, emission during manufacturing process and construction of the pavement. Further it has considered the sound levels that are generated during the operational stage of the pavement. From the comparison of those facts it can be concluded that NRMB and CRMB is more environmentally feasible over the CB. This is mainly because of the less use of natural recourses and the reduction of sound level to 30-40 dB from 60-70 dB of CB.

Social impacts have been studied in terms of cost to the vehicle user, risk of accident occurring, disturbance during road maintenance, travel time saving due to the good condition of pavement. The study shows that both the NRMB and CRMB are better over the CB in this aspect also.

The conducted market survey revealed that the current market demand for NR is 70-75% of the production. This study has shown that the NR demand for modified bitumen rubber is less than 25% of the current production. Therefore, the demand can be satisfied without disturbing the current market as well as it will be a value addition to NR. Furthermore, CR will generate additional benefits as it is a recycling process, which would give answers to prevailing issues relating to rubber waste. Most importantly it will help reduce the environmental and social problems that are created due to waste tyres.

The market survey also revealed that, the production cost of modified bitumen is not severely dependent on the cost of rubber. Hence, the current market price for CR can be increased without much affecting cost of the final product. This will be an incentive to the public to interest them to motivate to recycle rubber; which will be an added advantage.

Therefore, it can be seen that using CRMB is more appropriate to Sri Lankan context. Although the market study has revealed that there is not enough CR in the local market they can easily be imported. However, the associated environmental, social and economic impacts of such strategy need to be further studies prior to any actual importation, owing to the fact that there is not enough research conducted on that area in the Sri Lankan context. Based on the market survey it was found that, price of CR will increase by 20-25% when importing for CRMB, even so, the impact of it will be not significant on the final output compared to total cost of NRMB. To end with, owing to the technical feasibility, economic, social and environmental impacts and especially due to the market situation, it can be concluded that Crumb Rubber Modified Bitumen is more appropriate to Sri Lankan road construction a as a modified bitumen.

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