BITUMEN MODIFIERS FOR IMPROVED PERFORMANCE IN PAVEMENT TECHNOLOGY

by

Dr. M.J. Fernando and Eng. D.P. Mallawaratchie

Abstract

Properties of modifiers for bituminous binders have been reviewed. Extensive laboratory and field experiments have shown that Natural Rubber is an excellent Elastomer to modify bitumen for road making under severe conditions of climate and traffic. Work is underway to incorporate Natural Rubber on a large scale to penetration grade bitumen and emulsions.

Introduction

In recent years it has been observed that pavement structures of major highways in many countries have failed to achieve their design life. Traditional bituminous binders are limited by their performance under heavy traffic and in adverse climatic conditions and their use in certain situations causes considerable problems. Furthermore road axle loads have increased considerably and there is evidence that this trend will continue in the future.

Rutting caused by permanent deformation within bituminous pavements has caused concern. Bleeding of the surface at high road surface temperatures and lack of adhesion with aggregate in the presence of water have been widespread.

In Sri Lanka, low life span of sand seals using bituminous emulsions and manual methods on medium and heavily trafficked roads is also causing concern. Oil spillage and resultant failure of surfacing on our roads, airport runways and aprons is also another problem that has to be solved. A continuous and concerted effort is therefore necessary to define and develop new and or modified materials which will lengthen the useful life of bituminous applications, surface dressings and surfacing.

Modified binders have shown their ability to improve performance in other countries compared with traditional road binders. Hence in Sri Lanka too, the time has come to consider a change in the traditional system of preparing mixes based on traditional binders.

As the annual consumption of bitumen for Road Development Authority (RDA) works is about 10,000 tonnes costing about Rs. 175 Million, it is important that we make use of this material in the most cost effective way by suitably modifying the same.

In recent time, there is considerable interest in bitumen modifiers (EPPS 1986) to produce better asphalt systems because the price of asphalt has risen by a factor of five since 1973 and the wide spread fear that the quality of a bitumen has changed since the oil embargo, as often cited by field engineers to be the cause of tender mixes, plastic instability, thermal cracking, ravelling and water susceptibility of the pavements.

Classification of Modifiers

Currently there are various types of modifiers, capable of improving the performance of bituminous binders. A general classification of available modifiers is given in Table 1.

A modifier must, be readily available, easily blend with bitumen or incorporated with bituminous emulsion, improve resistance to flow at high road temperatures, be not too viscous at mixing and laying temperatures and be cost effective. The modified bitumen prepared with modifiers should maintain its consistency during storage, construction & service, be processed by conventional equipment and achieve a spraying or coating viscosity at normal application temperatures.

Dr. M.J. Fernando, *Consultant (Highway Materials), World Bank 3rd Road Project - WB3/5A & 5B (Resources Development Consultants Ltd.),*

Eng. D.P. Mallawaratchie, *Director (Research & Development), Research & Development Division, Road Development Authority.*

TABLE 1

CLASSIFICATION OF MODIFIERS

TYPE	EXAMPLES
1. MINERAL FILLERS	DUST, LIME, PORTLAND CEMENT, CARBON BLACK, SULPHUR
2. EXTENDERS	SULPHUR, LIGNIN
3. RUBBERS	NATURAL RUBBER, SYNTHETIC RUBBER, RECYCLED RUBBER
4. PLASTICS	POLY ETHYLENE, POLY PROPYLENE, E.V.A., P.V.C.
5. COMBINATIONS	POLYMERS IN 2, 3, 4
6. FIBERS	ASBESTOS, ROCK WOOL, POLY PROPYLENE, POLY ETHYLENE
7. OXIDANTS	MANGANESE, OTHER MINERAL SALTS
8. ANTI-OXIDANTS	LEAD COMPOUNDS, CARBON, CALCIUM SALTS
9. HYDROCARBONS	RECYCLING OILS, REJUVENATING OILS
10. ANTI-STRIPPING MATERIALS	AMINES, LIME

Sometimes it would be necessary to use two or more modifiers to achieve the desired end and such a process may be expensive.

Of various modifiers used, organic polymers such as rubbers and plastics are widely used to achieve the desired effect. Natural rubber, synthetic rubber, block copolymer, reclaimed rubber and plastics such as polyethylene, polypropylene, ethylene-vinyl acetate and polyvinyl chloride are common modifiers.

Properties of an ideal modifier

The properties of an ideal modifier are illustrated in Figure 1 by taking into consideration the variation of stiffness of Asphalt binders versus temperature. There are three distinct temperature ranges denoted by Low Service Temperature (L.S.T.), High Service Temperature (H.S.T) and Mixing Temperature (M.T). Normally the Compaction Temperature (C.T) range is between 80° - 130° C.

The ideal modified bitumen aggregate mix (shown by broken line) should have the following when compared to conventional asphalt aggregate mix (solid line):

i. Lower Stiffness Modulus at L.S.T (-45° to -4°C) to avoid brittle fracture

ii. Higher Stiffness Modulus at H.S.T (58° to 79°C) to impart high thermal stability and hence to reduce rutting, permanent deformation or distortion and bleeding

iii. Lower Stiffness Modulus at C.T. (80° - 130°C) and M.T. (121° - 149° C) to improve workability at normal working temperatures

iv. Improved adhesion

v. Low temperature susceptibility

vi. Improved durability and

vii. Cost effectiveness

One draw back of the use of modified bitumen is the increased viscosity that it occurs at normal mixing temperature depending on the type and quality of modifier used, the equiviscous temperature may rise upto 20°C. Hence more fuel may be required.

Modifiers Relevant for Sri Lanka

Natural rubber is characterized by weak inter-molecular forces, small degree of steric hindrance and relatively low energy of molecular cohesion. These factors make it an excellent elastomer to modify asphalt. The persistent elastic response of the rubber asphalt system is primarily due to entanglement of the flexible long chain molecule together with some chemical interaction. (DENNING & CARSWELL 1981, SEKHAR 1963, FERNANDO & NADARAJAH 1969)

Sri Lanka is a well known, natural rubber producing country in the world. Natural rubber latex is readily available and it is very cheap. Hence it is the obvious

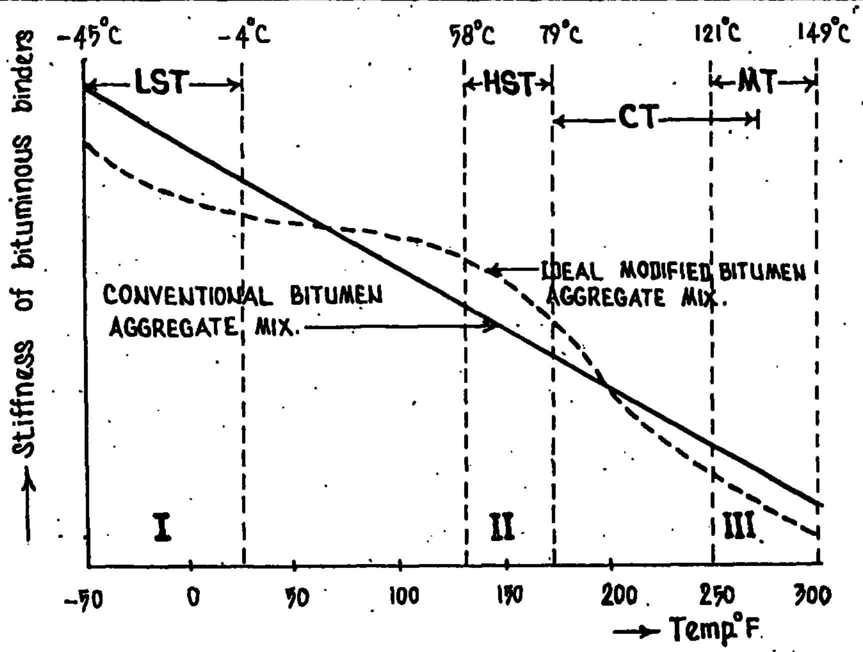

FIGURE 1 - PROPERTIES OF AN IDEAL BITUMEN MODIFIER (REF: EPPS 1986)

choice for the preparation of modified bitumen in road construction.

Today, the Road Engineer is faced with the challenge of designing and constructing roads to cope with the intensity of traffic, different wheel loads, weather conditions etc. and at the same time more durable, comfortable and cheaper roads with locally available raw materials. To meet this challenge a systematic programme of study was launched for the first time in Sri Lanka as early as 1966 to develop a new product for road surfacing with locally available rubber latex and bitumen from our petroleum refinery, at the Research and Development Office of the, then Highways Department, followed with field trials in all parts of the country.

Latex is the most effective form of natural rubber for road construction. Both centrifuged latex and revertex being used. Creamed skim latex was found to be the most effective for road making. Because of easy availability, however, suitably stabilized field latex is more suitable for road making in the natural rubber producing countries. (FERNANDO 1967), over twenty different types of lattices have been experimented with at the R&D office, Ratmalana.

Experimental Work

Mixing

In small scale field works carried out from 1966 to 1975, when latex is added little at a time in its natural form to hot bitumen at 150 - 180°C, it is first dispersed into fine particles of rubber. These particles swell and then commence to dissolve under the action of prolonged heat. They finally dissolve to give a rubbery material known as "Rubberized Bitumen". The particle dispersion has a pronounced effect on the properties of the final product used for road construction. Other factors that have an influence on the physico-chemical properties of bitumen are

i. the type and amount of rubber
ii. the temperature and duration of heating and
iii. the source and type of Bitumen

Whatever the form of rubber used and whatever the method of blending employed, the ultimate object is to prepare a rubberized binder containing the maximum possible effective rubber content or a rubberized bitumen in which the rubber content has suffered minimum degradation during blending. A high degree of uniform dispersion of rubber throughout bitumen should be maintained during mixing.

Results and Discussion

Addition of a small quantity of natural rubber (2 - 4% by mass of bitumen) modifies the physico-chemical properties of asphalt significantly and produces a superior asphalt concrete in road surfacing especially for the type of environment and traffic conditions prevailing in tropical countries, Gulf countries and fast developing countries of South east Asia. (FERNANDO & GUIRGUIS 1983A, 1983B & 1984)

Natural Rubber modified bitumen is found to be

* More resistant to temperature changes
* Less bleeding or fatting up
* More resistant to brittleness
* Less rutting or permanent deformation
* More resistant to fatigue
* More durable
* Could be treated as a "Heavy Duty Bitumen"
* Design thickness may be reduced
* More economical

Under hot climates, rutting or distortion is a common distress mode associated with heavy axle loads. Rubber modified asphalt concrete is very resistant to rutting Figure 2 illustrates this effect.

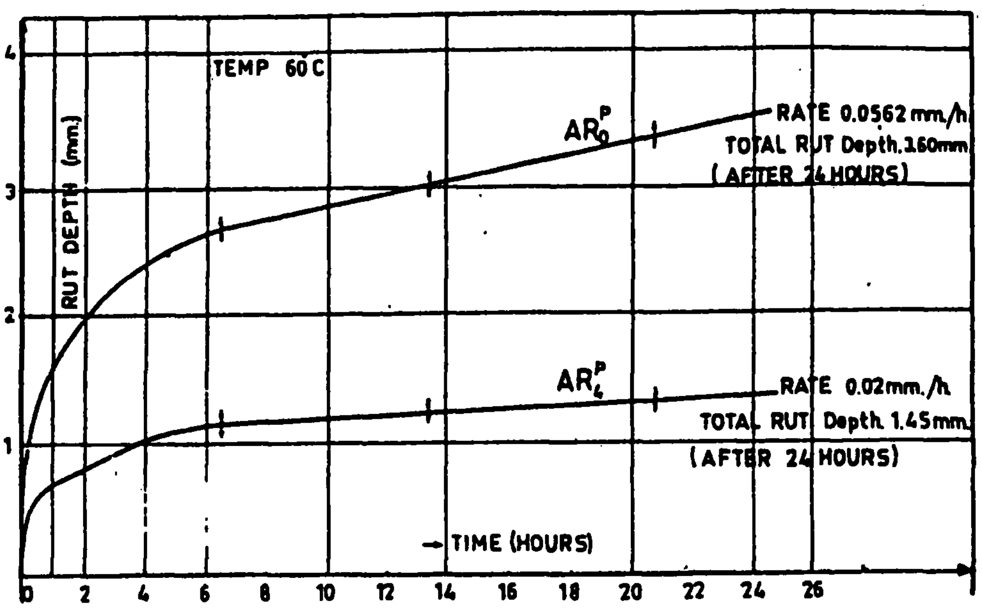

Fig. 2 Rut Depth Vs Time (Wheel) tracking test.
(Ref: Fernando 1983-B)

Some quantitative data for natural rubber modified binder and asphalt concrete (A.C) are given in Table II and Table III. The effectiveness of natural rubber modified bitumen is clearly evident.

TABLE II

SOME RESULTS OF RUBBERIZED BITUMEN

Three levels of rubber viz. 0,2,4, percent dry rubber content by weight of asphalt were used and designated as ARO, AR2, AR4.

PROPERTY	ARO	AR2	AR4
Penetration (0.1 mm, 25^0 C)	66	54	46
Softening point ^{0} C (R+B)	53	58	61
Frass Brittle point ^{0}C	-21.0	- 22.5	-25.0
Viscosity at 60^0 C(increase as a ratio)	1.0	2.5	5.5
Temperature Susceptibility (reduction as a ratio)	1.00	1.76	2.22
Durability on Thin Film Oven Test (TFOT) (increase as a ratio)	1.00	1.46	2.54
Stiffness Modulus at 45^0 C, 1 Hz, (N/sq.m)	$5.5x10^7$	-	$1.1x10^8$

Note: Based on Penetration and softening point data, AR4 falls into the category of "Heavy Duty" bitumen.

TABLE III

SOME RESULTS OF RUBBERIZED ASPHALT CONCRETE MIXES

PROPERTY	ARO	AR2	AR4
Rut depth after 24 hrs. (mm)	13.3	3.6	2.2
Rutting rate (mm/hr) (wheel tracking test)	0.056	0.039	0.020
Resistance to water. Index of Retained Strength (IRS)% (Immersion compression test)	79	91	92
Fatigue life improvement (as a ratio at 20% Pu. $3x10^{-2}$ strain)	1.00	1.81	6.16
Permanent deformation at temp.45^0 C, 4 Hz, 0.138 MPa (No. cycles at strain $3x10^{-3}$)	$2.6x10^4$	$1x10^5$	$5x10^6$

Field Experiments

Rubberized roads are becoming increasingly popular in Western Countries, USA, Australia, Japan, Malaysia & Russia. Surface dressings using emulsions, rubber modified emulsions are extensively used in France for road construction.

The only effective way of studying the full potentialities of rubber on our roads is by laying experimental road sections using rubberized bitumen. From 1966 to 1975, the R&D Office with the assistance of the district engineers and Rubber Institute, at least 20 road sections have been laid in different parts of the country using very basic equipments and improvised apparatus to observe the effect of rubber latex on

a) Asphalt Concrete (Premix)

b) Penetration macadam

c) Seal coat surface treatment and

d) Subsequent (bituminous) coat

These road sections were found to be more resistant to weather and traffic specially at roundabouts, steep gradients and places involved with stopping and starting of heavy traffic. Above all these road sections remain serviceable for longer periods.

Since rubberized bitumen has a higher viscosity at compaction and mixing temperatures, the equiviscous temperature should be about 5^{o} - 8^{o}C more than for conventional bitumen.

Under local conditions of environment and traffic, the rubberized road sections had given 50 - 65% more service life.

Other forms of modifiers

In Sri Lanka natural rubber powders such as buffing dust obtained from retreading tyre industry is a suitable candidate to modify road bitumen. More recently attention has been directed to the use of large amounts of cheap, scrap rubber from discarded tyre in bitumen. The main application of tyre waste in US has been for the treatment of cracked surfaces as a strain alleviating membrane (SAM) or as a strain alleviating inter layer (SAMI) where 18 - 26% tyre powder by mass of asphalt concrete is used (MORRIS & MC DONALD 1976). In another study smaller quantities of tyre waste has been used with natural rubber (FERNANDO & MESDARY 1990).

In recent times, the concept of recycling pavement material has drawn the attention of the highway engineer in a significant manner. Some studies have been conducted with old road pavement material rejuvenated with NUFLEX 330 and further modified with natural rubber (FERNANDO & MESDARY 1986).

An interesting study was carried out to study the effect of sulphur and natural rubber together in small quantities for road making (FERNANDO ET AL 1985)

MANUFACTURE OF RUBBERIZED A.C.

Asphalt concrete with rubberized bitumen could be manufactured by several methods such as

i. Pre-blending with bitumen

Addition of rubber in latex form is extremely effective and less expensive. As a result of water in latex there can be foaming when heated with bitumen. This foaming could be overcome by the addition of a suitable antifoaming agent (eg: Midland Silicone Antifoam 'A') where necessary.

ii. If unvulcanized rubber powder is used

It could be added very easily like filler to aggregate in a mixing box.

iii. Adding latex at Plant level

Latex could be added by

* Installation of a metering device for latex in separate tank interlocking with bitumen line.
* Installation of a device to spray latex to the bitumen coated aggregate in a mixing box.

Quality Control

In any type of road construction or use of materials in a rapidly developing country, the importance of quality control cannot be overemphasized. For quality control of natural rubber modified asphalt the following methods may be used.

1) For latex:-

Determination of dry rubber content (d.r.c) using acetic acid or suitable reagent.

2) For rubberized Bitumen :-

a) Determination of Total rubber content (R_T)

b) Determination of Effective rubber content (R_{eft})

$$a)\ R_T = \frac{I - E}{374 - E} \times 100K \quad \% w/w$$

Where I = Iodine value of the acetone insoluble fraction of rubberized bitumen (RB)

E = Iodine value of the acetone insoluble fraction of bitumen (B)

K = Fraction of RB insoluble in acetone

$$b)\ R_{eft} = \left[\eta_{sp} - C\right] dK \quad \% \text{ by wt.}$$

$$\text{Where } \eta_{sp} = \frac{\eta_{\text{of solution}}}{\eta_{\text{of solvent}}} - 1$$

η_{sp} = (specific viscosity) could be determined using an Oswald viscometer at 25°C.

C = Constant for Bitumen (0.35)

d = Constant for natural rubber (3.35)

K = Fraction of RB insoluble in acetone

APPLICATIONS

In view of excellent improvements observed, rubberized bitumen could be used with advantage for the following:-

i. Asphaltic concrete for the construction of new roads and overlays, rehabilitation of existing roads using bitumen bound bases as correction courses specially when the traffic is heavy and the climate is hot where penetration grade of bitumen is used.

ii. Sand seals, single bitumen surface treatments, and double bitumen surface treatments using rapid setting emulsion.

In Europe, modified binders are being used increasingly at more severe sites because they appear to reduce the risk of premature failures.

iii. Cold mixes for correction courses and surfacing for existing roads and slurry seals for sealing surfaces by using slow setting emulsions.

iv. Thin surfacing by using penetration grade of bitumens to cut down costs.

In views of the above, the following are already underway with the assistance of Road Construction & Development Company, Rubber Research Institute and Chemical Engineering Department, University of Moratuwa:-

i. Natural rubber latex and also powders (buffing dust) obtained from retreading industry to be incorporated at the bitumen aggregate mixing plant at Peliyagoda.

ii. Natural rubber latex to be incorporated with cationic emulsions (CRS-1, CRS-2, and CSS-1) at the Angulana emulsion manufacturing plant.

iii. Natural rubber latex to be incorporated with anionic emulsions at the Angulana emulsion manufacturing plant.

iv. Manufacture of rubberized cationic emulsion using rubberized bitumen.

Conclusion

Sufficient laboratory and field experiments have been carried out in Sri Lanka and other countries to prove that natural rubber is an excellent modifier for bitumen. Hence it is time that all the relevant Engineers, Technologists and Scientists of the country get together and work out all the necessary details to incorporate natural rubber to penetration grade bitumen and emulsions on a wide scale to improve our net work of roads, so vital to the overall development of Sri Lanka.

Acknowledgement

The authors wish to thank the Secretary to the Minister of State for Highways and Chairman and General Manager, Road Development Authority for granting permission to present this paper. They also wish to thank all those who have helped in the preparation of this paper.

References

DENNING J H and CARSWELL, J (1981). Improvements in rolled Asphalt surfacing by the addition of organic polymers. TRRL Report 989.

EPPS, J (1986). Asphalt Pavement Modifiers - Engineering Design and construction, Civil Engineering (ASCE), April, pp 57-60.

FERNANDO, M.J (1967) - Use of Rubberized Bitumen in Roads - paper presented at the 23rd Annual Session of the Ceylon Association for the Advancement of Science Colombo, Ceylon (December)

FERNANDO, M.J and GUIRGUIS, H.R (1983a) - Benefits of rubberized Bitumen under high working temperatures - Proc. Annual Conf. International Road Federation, Libreville, Gabon Africa (Feb 6-11)

FERNANDO, M J and GUIRGUIS, H.R (1983b) - Rubberized Asphalt in pavement technology for hot climates, 4th REAAA Conf. Jakarta, Indonesia Aug. 22-26. Proc. Vol. 3 pp. 25-44.

FERNANDO, M J and GUIRGUIS, H.R (1984) - Natural rubber for improved surfacing - 12th ARRB Conf. Hobart, Australia, Proc. Vo. 12 Part 2, pp 121 - 130

FERNANDO, M J et al (1985) - The effect of sulphur and Rubber in modifying binders for Asphaltic Road Materials - 2nd Arabian Regional Conf. on Sulphur and its uses, Riyadh, Saudi Arabia, Proc. Vol. 3, pp 411 - 433 (March).

FERNANDO, M J and MESDARY, M S (1986) - Potential Advantages of Recycling Asphaltic Concrete with Natural Rubber - 13th ARRB/5th REAAA Conf. Adelaide, Australia, (Aug) Proc. Vol. 13, Part 3. pp 145 - 151.

FERNANDO, M J and MESDARY, M S (1990) - Effect of ground tyre waste as an additive to Rubberized Asphalt on Road Performance 6th REAAA/15th ARRB Conf. Kuala Lumpur, Malaysia, Proc. Vol. 1 Technical Session 5, Road Maintenance II (March)

FERNANDO, M J and NADARAJAH M (1969) - Use of natural Rubber Latex in Road Construction - J. Rubber Research Institute, Malaysia, Vol. 22 (5) pp 430 - 440.

MORRIS, G R and MC DONALD, C. H (1976) Asphalt - Rubber Stress Absorbing Membranes, Field Performance and State of the Art, TRB, USA, Record 595, pp 52-58.

SEKHAR, B.C. (1963) Abnormal groups in Rubber and Microgel, Proc. Rubber Technolgoy Conf. London 1962, 460.