J nat Rubb Res, **11(3)**, 166–182

Properties of Rubberised Bitumen from Reclaimed Rubber[†]

AZEMI BIN SAMSURI[*]

This paper discusses the properties of rubberised bitumen prepared by physical blending of bitumen with reclaimed rubber powders obtained from either rejected rubber gloves or scrap tyres Besides reclaimed rubbers, natural rubber latex and synthetic polymer such as ethylene methyl acrylate were also used to prepare the rubberised bitumen Properties such as penetration number, softening point, work done to break and tenacity were measured, results showed that the properties improved with the addition of rubber The softening point, tenacity and energy to break increased progressively while penetration number decreased with increasing rubber content. Rubberised bitumen prepared by using glove crumbs produced overall better properties than that using tyre shavings The properties of rubberised bituminous mixes were also evaluated and compared with those of ordinary bituminous mixes The results showed that rubberised bituminous mixes produced higher resistance to permanent deformation and dynamic cracking compared with ordinary bituminous mixes

Some materials are easy to recycle while others are difficult. Thermoplastic products are easy to recycle and can be moulded into products again simply by the application of adequate heat and pressure. In contrast, most rubber products and thermoset plastics are not easy to recycle and cannot be moulded directly into products again because of the three dimensional crosslink network which prevents flow Thus, most of the scrap rubber products such as used tyres or rubber discards are presently burnt or buried in designated landfill areas. Both methods are environmentally unfriendly. However, by means of a suitable reclaiming process, reclaimed rubber in the form of fine powders (40 mesh or 420 microns) can be produced from these scrap rubber products (tyres, examination gloves, toy balloons, *etc.*). These fine powders can be used to aid processing such as in extrusion and calendering to reduce extrudate swell and shrinkage and thus provide an overall better dimensional stability. Besides processing aids, reclaim rubbers can be used as extenders to cheapen the compounding costs at the expense of slightly poorer physical properties of the final vulcanisates.

Another important area where fine rubber powders find a wide application is in the construction of flexible road pavement Currently, an ordinary unmodified bitumen which serves as a binder (a substance used to hold the aggregate structure firmly together or to a substrate) in a wearing course is not adequate to meet the ever increasing traffic/

[†]Paper presented at IRC '96 Manchester, UK (Organised by The Institute of Materials, London)

[*]Rubber Research Institute of Malaysia, P O Box 10150, 50908 Kuala Lumpur, Malaysia

axle loads. It is well established that flexible pavements need relaxation time for recovery, a phenomenon known as healing[1]. If the traffic is not heavy (off-peak traffic hours), the small stress cracks within an asphalt pavement will tend to heal or close with time. However, under a very heavy traffic condition, the cracks have little time to heal, thus accelerating pavement failure. Apart from heavy axle loads, climatic factors such as high temperatures and intense heat can also accelerate pavement failure through rapid ageing of bitumen. An aged and degraded bitumen is a hard and brittle material which may form cracks easily due to cyclic stresses associated with traffic loads and expansion and contraction due to thermal changes. The cracks formed will eventually lead to premature failures of road surfaces. If precautions and means of overcoming premature road failures are not carried out, the Public Works Department and Highway Authority will continue to pay a very high cost for road maintenance and repairs. Furthermore, driving on defective road surfaces is both uncomfortable and unsafe.

Increasing demands on road surfacings posed by higher traffic density, heavier loads and faster speeds emphasise the need for binders with improved performance. It is in this area that rubberised binders have a role to play. Quite small quantities of rubber improve the cohesive strength of bitumen; the latter becomes tougher and more tenacious than unmodified bitumen[2]. Rubber makes the bitumen less brittle and increases the range of temperatures over which it remains serviceable; the flexibility which rubber imparts allows it to hold more securely to aggregate against displacement forces[2]. The addition of rubber particulate increases the viscosity of the bitumen cement and, thereby, improves the bitumen's film thickness on the aggregates, allowing the hot mix to hold more binder content and at the same time reduce the absorbency of aggregates[1]. This, in turn, can help optimise the binder content to the advantage of the pavement design-engineer.

The studies on the incorporation of rubber and synthetic polymer into bitumen to improve the properties of the binder for road pavement date back to the 1930s[3]. The usage of polymer-modified bitumen to improve the performance of pavement system is now widely adopted in Europe, United States of America and Australia. However, the knowledge and technology regarding the use of natural or synthetic rubber as an additive to bituminous binder are still relatively new in the South East Asian regions. In view of this scenario, colloborative work was undertaken by the Rubber Research Institute of Malaysia (RRIM) and Public Works Department Research Institute (IKRAM) with a view to provide knowledge and information to the local road engineers on the use of natural rubber additive to modify the bituminous binder as a means or an alternative to overcome the problems of premature failure of road pavement.

This paper discusses some of the laboratory studies and limited service trial of rubberised-bituminous mix to explore the usage of fine rubber powders as bitumen modifier in making road pavements. The fine rubber powders were produced from natural rubber examination glove rejects and tyre shavings, respectively. Apart from reclaimed rubber, natural rubber latex concentrate and polyethylene-co-methyl acrylate (EMA) were also used to modify the bitumen. The performance of rubberised-bitumen based on fine rubber powders obtained from scrap rubber goods was compared with that of rubberised bitumen based on natural rubber latices and also with that of unmodified bitumen.

EXPERIMENTAL

Materials

Four different types of rubber were used *viz.* natural rubber (NR) latex concentrate, pre-vulcanised NR latex, fine rubber powders reclaimed from rejected examination gloves (particle size of 0.5 mm) and tyre shavings (particle size of 0.5 mm). Commercial grade EMA was also used to modify the bitumen (details of technical specifications were not disclosed). Bitumen of 80/100 penetration number was used throughout unless stated otherwise.

Mixing

Mixing was carried out on a laboratory scale using a Hobart mixer at a temperature of 160°C for about 1.5 h. First, the solidified bitumen was heated until it melted and in liquid form. On reaching the required temperature, the bitumen was blended with rubber at rotor speed of 80 r.p.m. The quantity of rubber was varied from 2 parts per hundred of bitumen (p.p.h.b.) to 10 p.p.h.b. Large scale mixing was carried out in a blending tank of 10 metric ton capacity; only the fine rubber powders reclaimed from reject examination gloves were used in the large scale mixes.

Road Trial

A rubberised-bitumen road trial using fine rubber powders from reject gloves and NR latex concentrate was carried out on the N1 Rembau road, Negeri Sembilan. The amount of rubber used was five percent of the binder content. The quantity of rubberised bituminous binder used was five percent by weight of the total mix aggregates. There were two methods of producing the mix. In the first case, the rubberised bitumen was first prepared by preblending fine rubber powders with bitumen in a 10 metric ton capacity tank mixer (as decribed above). Then, the preblended rubberised bitumen was mixed with the aggregates of different sizes at different proportions in accord with gradation SHRP mix design. Mixing of rubberised bituminous binder with the aggregates was carried out in a pugmill by using the batch process. In the second case, instead of preblending the rubber with bitumen, the rubber was added directly to bitumen and aggregates where they were mixed in the same pugmill. Samples were taken from the bituminous mix to prepare the cylindrical test-pieces by using a gyratory compactor which simulated field compaction. A pressure of 240 kPa was applied for 200 revolutions at 135°C. In this investigation, sample designated by SX 20 denoted a dense bituminous mix where unmodified bitumen was used as the binder. SX 20 + NR latex denoted a dense mix prepared by the second method where rubberised bitumen (based on NR latex) was used as the binder. SX 20 + glove crumbs denoted a dense mix prepared by the second method where rubberised bitumen (based on glove crumbs) was used as the binder. SX 20 + preblended glove crumbs denoted a dense mix prepared by the first method where rubberised bitumen was used as the binder based on preblended glove crumbs.

Physical Tests

Penetration number. The penetration number was determined according to *BS 2000: Part 49*, 1983. It is a measure of consistency of a bituminous material expressed as the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. In this test, the sample was melted and filled in a penetration cup (diameter 55 mm, internal depth 35 mm). Later, the sample was cooled and placed together with a transfer dish in water bath at $25 \pm 0.1°C$ for 1.5 h. The penetration was measured with a penetrometer by means of which a standard needle was applied to the sample under a fixed known load (100 g). The distance (depth) of penetration was measured after 5 seconds of loading.

Softening point. The softening point was determined using ring and ball apparatus according to *BS 2000: Part 58*, 1983 specifications. In this test, a steel ball of specific mass was placed upon a disk of bitumen contained within a metal ring of specified dimensions. The assembled apparatus was placed in a bath of liquid and the softening point was taken at which the bitumen surrounding the steel ball just touched the base of the apparatus.

Energy at break and tenacity. Rubberised-bitumen sample was melted by heating at a temperature of 120°C. The molten sample was poured into three mould brickets until it excessively filled the mould cavity and allowed to cool at 23°C. Once the sample solidified, the excessive material was removed with a hot knife. The sample was conditioned at 23°C for 24 h before testing. The stress-strain measurements on rubberised bitumen samples in a moulded bricket were carried out by using an Instron tensile machine at a temperature of 23°C. The crosshead speed was 500 mm per min. The typical load-deformation curve is as shown in *Figure 1* and *Figure 2* for unmodified bitumen and rubberised bitumen, respectively. The energy to break was determined by integrating the area under the load-deformation curve OYE. In the case of unmodified bitumen, it is difficult to locate the breaking point since the bitumen just continued to flow as shown in *Figure 1*. To overcome the problem, the breaking point was referred to that of the breaking point of the rubberised bitumen.

The tenacity was determined by integrating the shaded area as shown in *Figures 1* and *2*. A straight line was extrapolated from the straight portion of the curve to meet the x-axis. The tenacity is defined by the area bounded by the straight line and the curve in the flow region (unmodified bitumen) or the curve in the 'rubbery' region (rubberised bitumen) as shown by the shaded portion in the two figures.

Marshall Test. The test was originally developed by Bruce Marshall and is described in *BS 598: Part 3*, 1985. This test is used to measure the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus. In this test, a cylindrical specimen (diameter 100 mm; length 60 mm) was compressed diametrically at a constant rate (50.8 mm per minute), at 60°C until failure. The maximum load developed during the test, known as Marshall stability, and the deformation at the maximum load, known as the Marshall flow were measured. Marshall quotient was determined by dividing Marshall stability by Marshall flow.

Indirect tensile modulus and fatigue tests. Both tests were carried out using the materials testing apparatus for asphalt (MATTA) machine as shown in *Figure 3*. The machine consists of a loading frame which has a heavy,

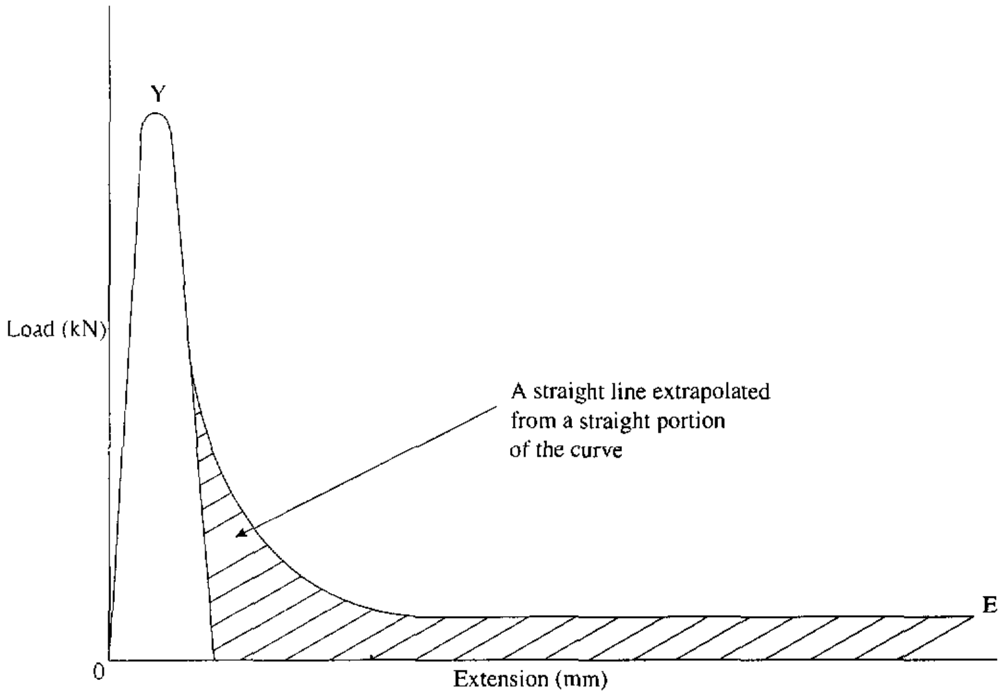

Figure 1. Load-deformation curve of unmodified bitumen.

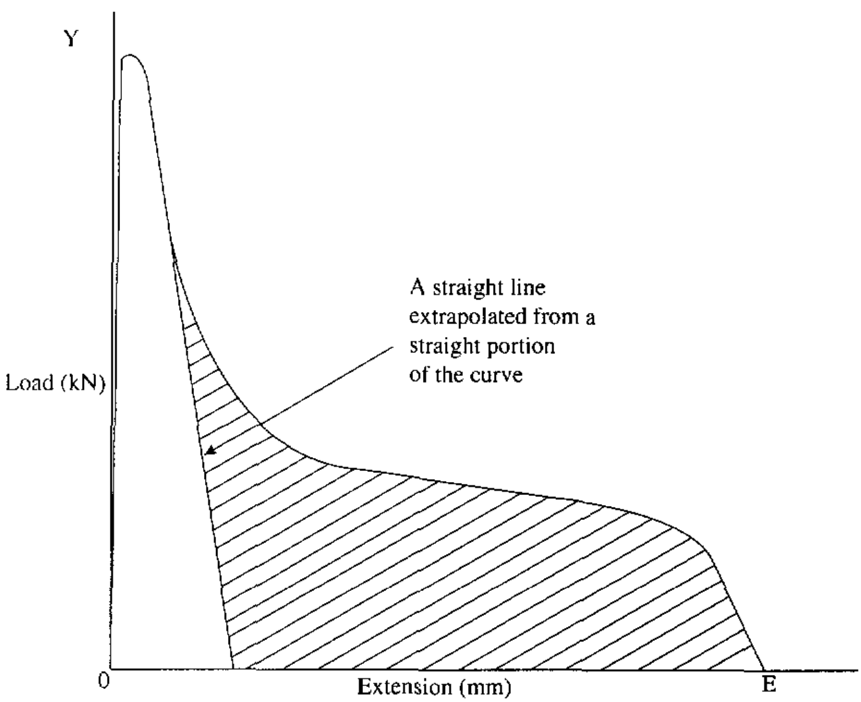

Figure 2. Load deformation curve of rubberised bitumen.

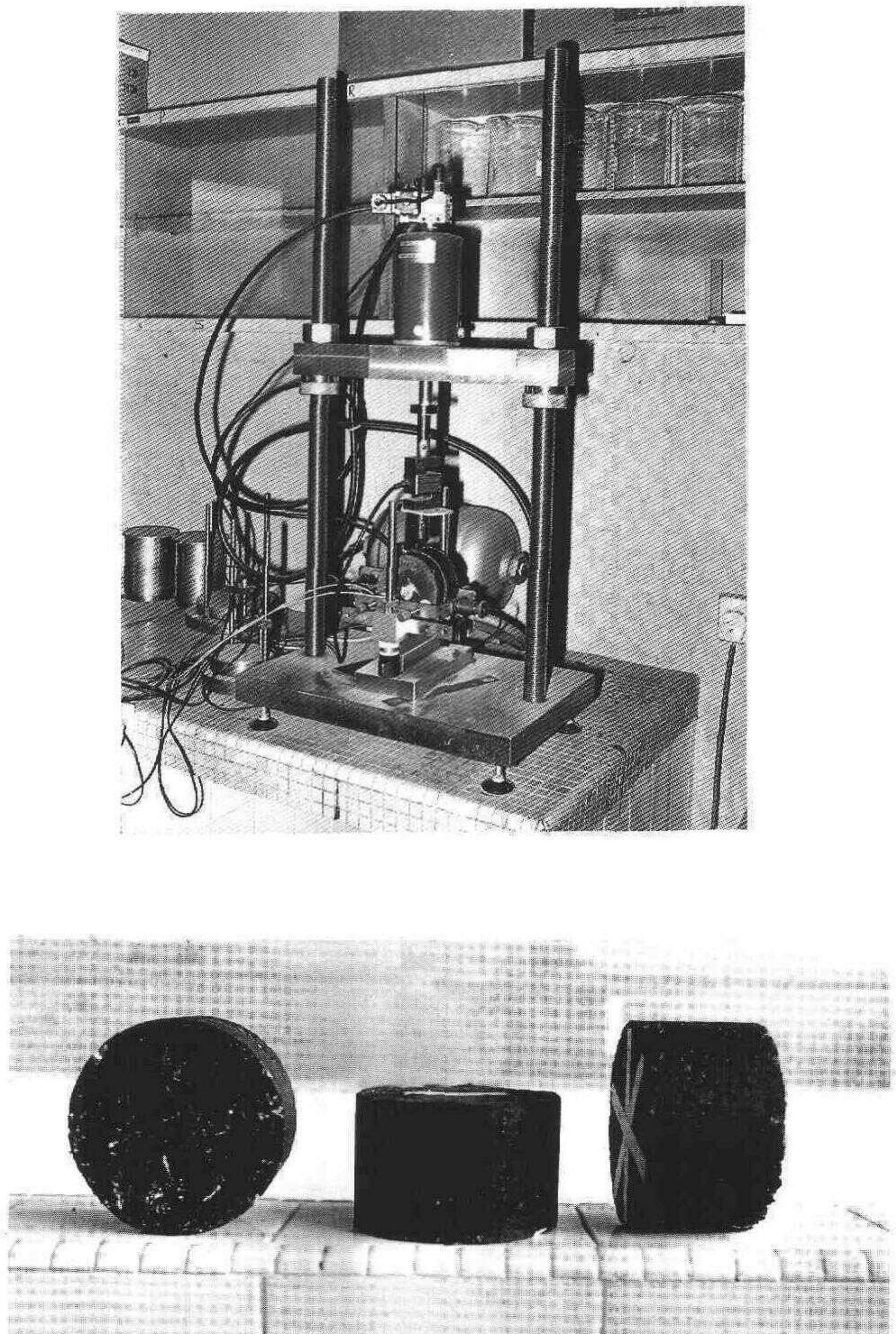

Figure 3. Photographs showing MATTA machine and test-specimen.

flat, baseplate, supported on four levelling screws. The frame is of heavy construction to limit deflection and vibrations which could influence the accuracy of measurements during dynamic repeated loading tests. Loading forces are applied through the shaft of a pneumatic actuator mounted in the centre of the crosshead A strain gauged force transducer, mounted in line with the loading shaft, measures the force applied to the specimen. The cylindrical specimen (as decribed above) is mounted in jigs that enable either indirect tensile or axial compressive loading.

The indirect tensile fatigue test provides facilities for repeated loading of the sample in indirect tensile mode for a maximum of one million pulses. Total and permanent strain together with modulus are continuously plotted against the number of pulses on logarithmic scales

RESULTS AND DICSUSSIONS

Properties of Rubberised-bitumen

Effect of type and quantity of rubber on penetration number. The effect of type and quantity of rubber on penetration number is shown in *Figure 4* where penetration number is plotted against rubber content, based on the data shown in *Table 1*. Unmodified bitumen is a soft and viscous material as reflected by its high penetration number, *i e* 85 8. The penetration number was affected both by the type and quantity of rubber All types of rubber showed a similar trend, *i e* the penetration number decreased progressively with increasing amount of rubber indicating the material became more viscous and harder. Blending rubber with bitumen results in a binder with improved hardness similar to harder grade bitumen. At more than 5 p p h.b EMA was the most effective in decreasing the penetration as reflected by the lower penetration number compared with rubbers as the modifier Among the rubbers, fine rubber powders reclaimed from reject gloves and prevulcanised NR latex were very effective in decreasing the penetration The result also showed that it required twice as much tyre shavings to get the same penetration number produced by the fine rubber powders from reject gloves. This might be due to higher rubber hydrocarbon content in reject gloves than in tyre shavings since the latter contained 40 to 50 parts p h r. of carbon black

Softening point. Figure 5 shows the plot of softening point *versus* rubber content, based on the data shown in *Table 2* Unmodified bitumen has a low softening point of about 44°C Incorporation of rubber into bitumen generally increases the softening point of the modified binder which has an advantage of the possibility of reducing the tendency to 'bleed' in hot weather which is a common problem for pavements in warmer climates[4] The plot in *Figure 5* shows a similar trend for each type of rubber The softening point increased progressively with increasing rubber content EMA modified bitumen produced the highest softening point followed by NR latex and fine rubber powders (reject gloves), while tyre shavings modified bitumen produced the lowest softening point among the rubbers The result again showed that it required at least twice as much or more tyre shavings to obtain the softening point produced from fine rubber powders of reject gloves which might indicate that, it is the rubber hydrocarbon content which predominantly modifies the bitumen.

Work done and energy at break Figure 6 shows the load-deformation characteristics of rubberised bitumen as well as the unmodified

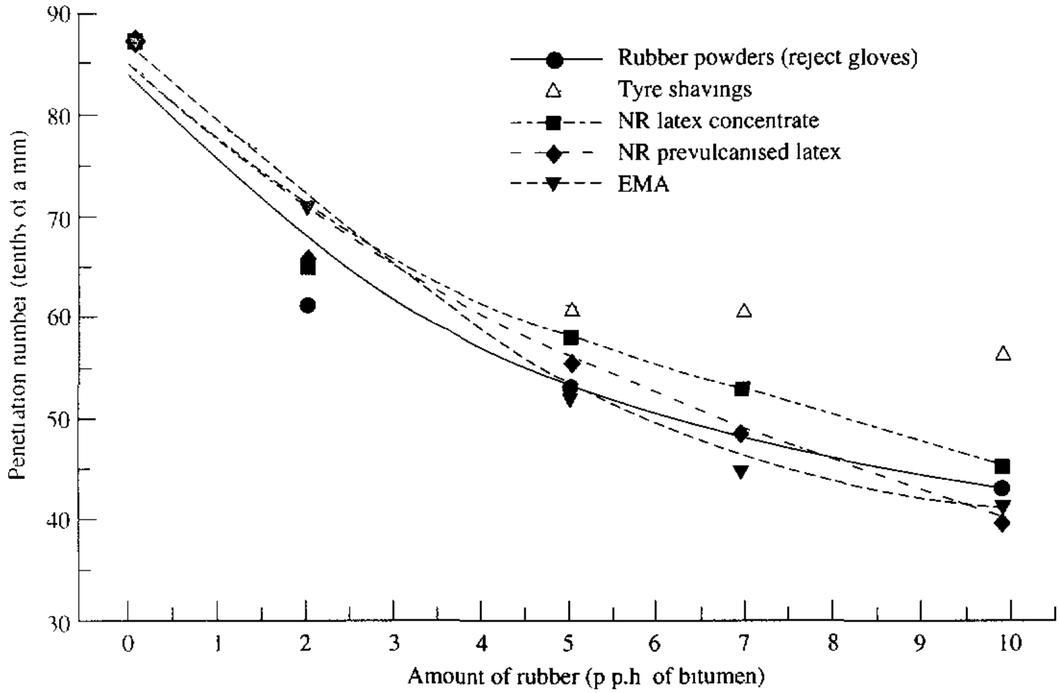

Figure 4 Penetration number vs *amount of rubber*

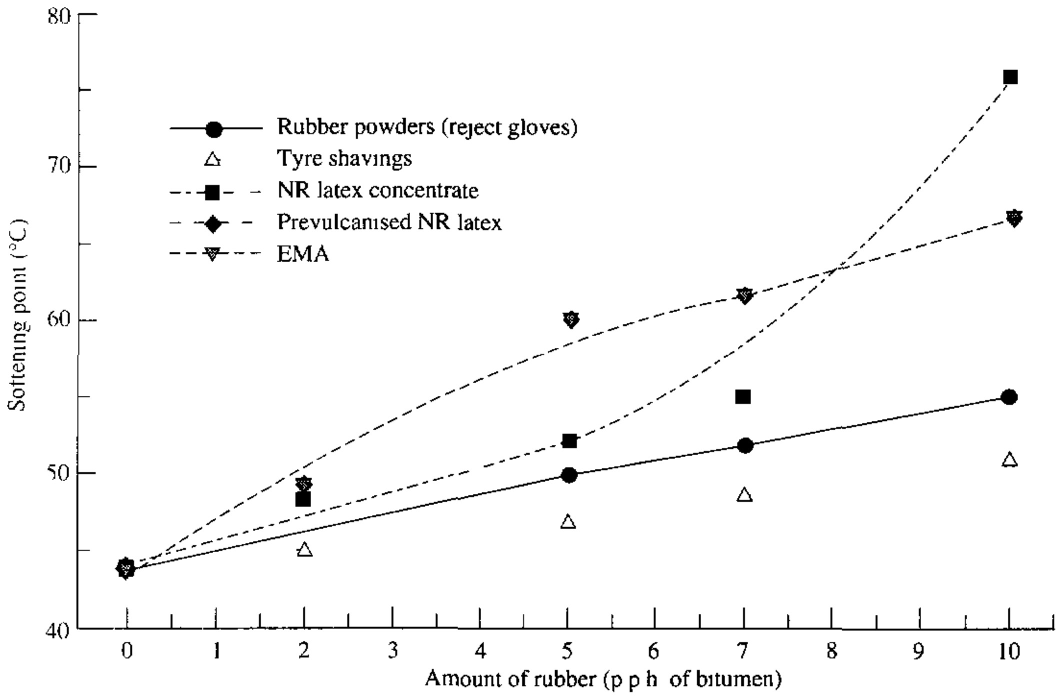

Figure 5 Softening point vs *amount of rubber*

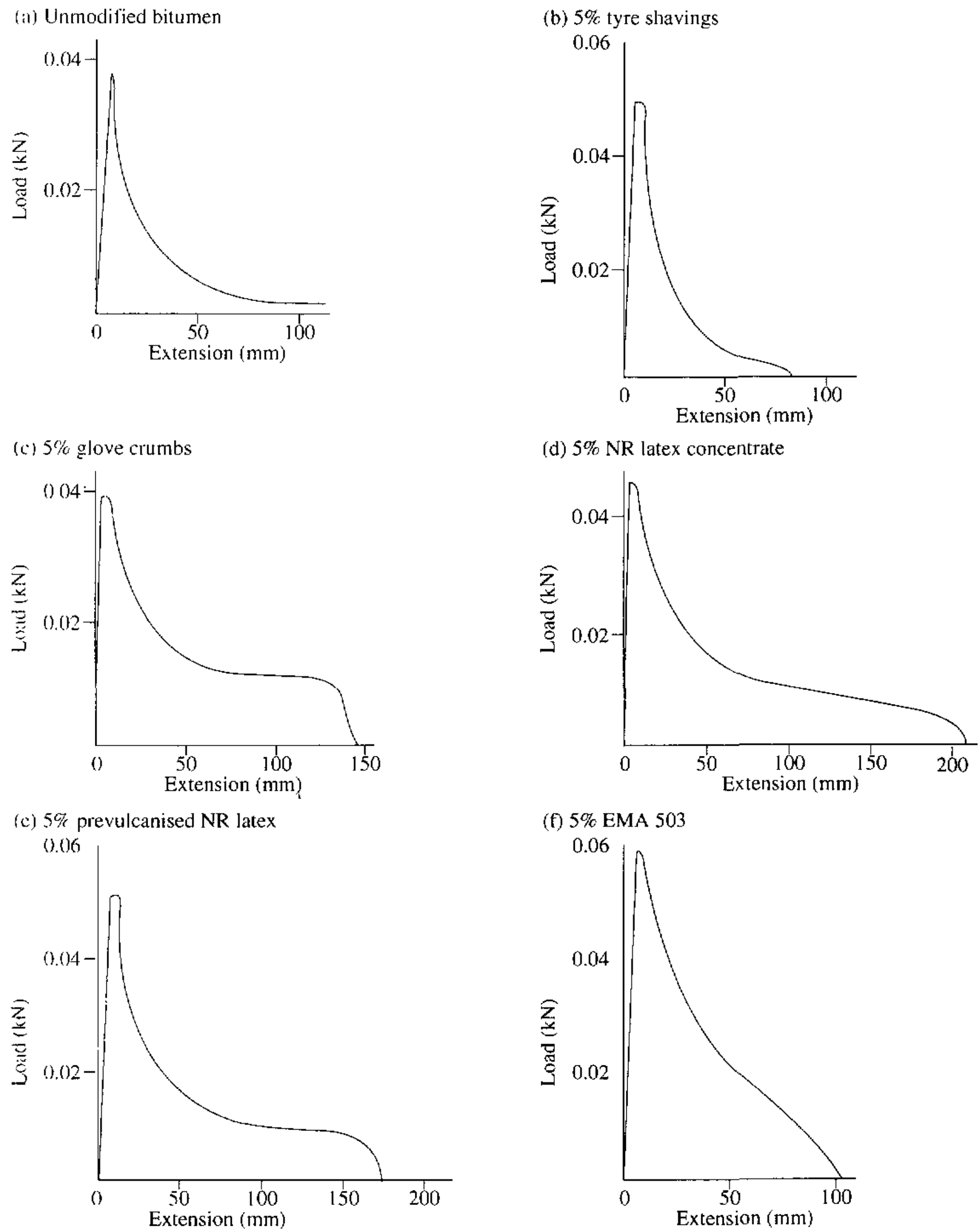

Figure 6. Load displacement characteristics of different types of rubberised bitumen reproduced from the chart recorded during the experiment.

TABLE 1 PENETRATION NUMBER (TENTH OF A MM) OF RUBBERISED-BITUMEN

Amount of rubber (p.p.h. of bitumen)	2	5	7	10
Rubber powders (reject gloves)	60.4	52.0	47.6	42.6
Tyre shavings	64.4	60.2	59.4	54.6
NR latex concentrate	64.4	57.0	51.8	44.4
Prevulcanised NR latex	64.8	54.8	47.6	39.4
EMA	69.2	51.2	44.2	41.0

Penetration number of unmodified bitumen = 85.8 (tenths of a m.m.)

TABLE 2 SOFTENING POINT (°C) OF RUBBERISED-BITUMEN

Amount of rubber (p.p.h. of bitumen)	2	5	7	10
Rubber powders (reject gloves)	47	50	52	55
Tyre shavings	45	47	48	50
NR latex concentrate	47	52	56	75
Prevulcanised NR latex	48	60	62	66
EMA	48	60	62	66

Softening point of unmodified bitumen = 44°C

bitumen and EMA-modified bitumen. The work done or energy to break was determined from the area under the load-deformation curve. The load-deformation curve was affected by the type of rubber (the amount used in each case was 5 p.p.h.b.). Unmodified bitumen produced a low maximum load after which the load decreased continuously producing a curve that looks like a rectangular hyperbola which asymptotes with the x-axis as the unmodified bitumen just continue its flow during deformation. In the case of rubber-modified bitumen, the maximum load increased markedly after which the load decreased progressively to a value about one third of its maximum load (in the cases of fine rubber powders from reject gloves and NR latices) before producing a 'rubbery' plateau region as a consequence of some degree of resistance to deformation attributed to the elastic behaviour of the rubber. Bitumen modified with tyre shavings and EMA did not produce broad plateau region; perhaps these materials are less rubbery since tyre shavings are filled with high concentration of black fillers and EMA is a plastic. Nevertheless, all modified bitumen binders showed a definite breaking point unlike unmodified bitumen which continued to flow like a thin thread even after the crosshead had reached its maximum permitted distance travelled.

The plot of work done or energy to break *versus* quantity of rubber is as shown in *Figure 7*. The unmodified bitumen when compared at the same breaking deformation as that of rubberised bitumen has the lowest energy, about 0.46 J, indicating that the material is weak and easily deformable. Addition of rubber into bitumen improved the energy to deformation significantly as reflected by the increase in the work done (energy) to break. Among the rubbers used, NR latex concentrate is the most effective in enhancing the energy to deformation, followed next by fine rubber powders from reject gloves. Addition of 5 p.p.h.b. of fine rubber powders from reject gloves, increased the energy to deformation by a factor of about four compared to that of unmodified bitumen. Thus, the results show that rubberised bitumen is very effective in enhancing the energy to deformation.

Effect of the rate of deformation on energy to break. The viscoelastic behaviour of rubber-modified bitumen was investigated by performing tensile stress-strain measurements at different rates of deformation at 23°C. This study is useful since in practice, the road pavements are subjected to different rates of cyclic loading as a consequence of different masses and accelerations of traffic axle loading. In this study, rubberised bitumen containing 5 p.p.h.b. of fine rubber powders reclaimed from reject gloves was subjected to different rates of deformation by pulling a sample in a mould bricket at different crosshead speeds ranging from 10 to 500 mm per minute using an Instron tensile machine. A similar exercise was also carried out for the unmodified bitumen. The results are shown in *Figure 8* where the energy to break is plotted against crosshead speed. Generally, the energy to break increased with increasing rate of deformation. The energy to break for both unmodified bitumen and rubberised bitumen increased by a factor of about four by increasing the crosshead speed from 10 mm per minute to 500 mm per minute. This is clearly a manifestation of the viscoelastic effects of the material. At any rate of deformation, the energy to break of rubberised bitumen is always higher than that of unmodified bitumen by a factor of about two at the lowest rate and by a factor of about four at the highest rate of deformation.

Tenacity. High tenacity is required for bitumen to be used in drainage mixes for good and long service performance[5]. A plot of tenacity *versus* amount of rubber is as shown in *Figure 9*. Unmodified bitumen produced a low tenacity value, 0.17 J. Addition of rubber into bitumen improved the tenacity of the modified binder. NR latex concentrate appears to be the most effective in enhancing the tenacity of the modified binder, followed by fine rubber powders from reject gloves.

Properties of Rubberised-bitumen Mix

Marshall test. The Marshall test can be used to predict the resistance to permanent deformation of bituminous mixes on the basis of empirical relationships. The Marshall quotient has been found to correlate with permanent deformation better than either the individual value of stability or flow. The results of the Marshall test are shown in *Table 3*. The addition of rubber give rise to an increase in the Marshall stability and quotient. The increase varies with the form of rubber used and the method of incorporating the rubber into

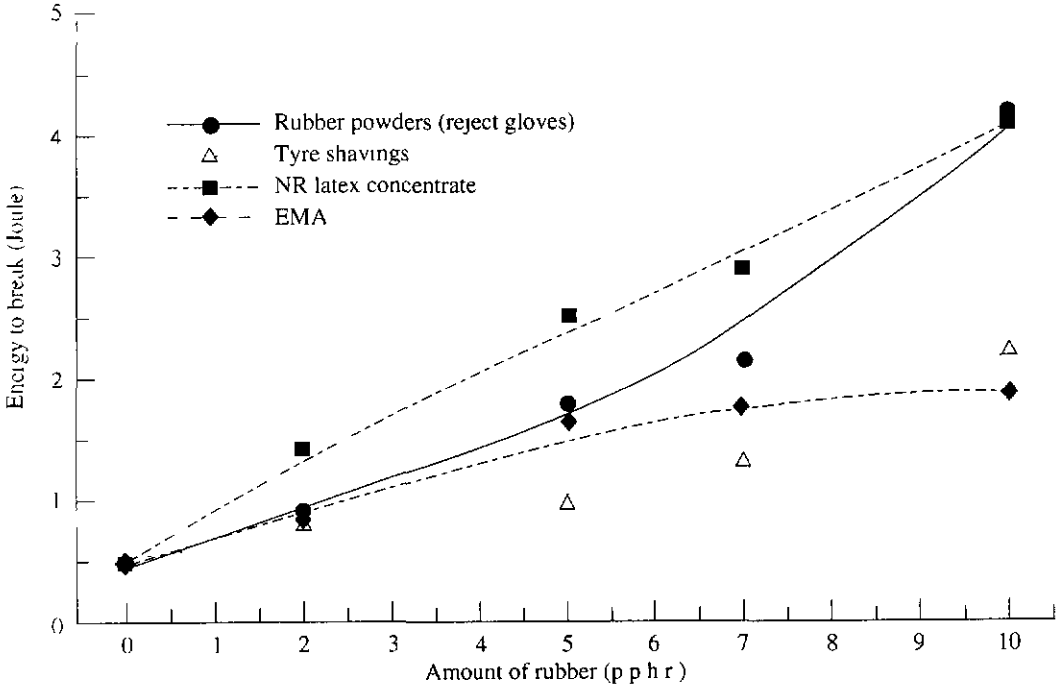

Figure 7 Energy to break vs amount of rubber (crosshead speed 500mm/min at 23°C)

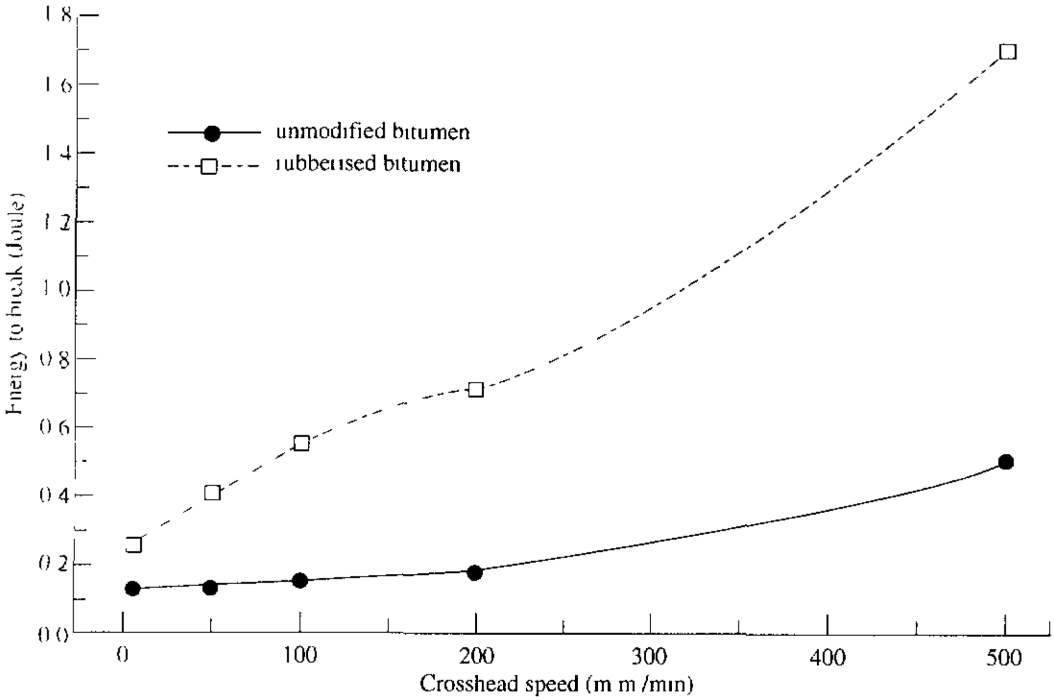

Figure 8 Energy to break vs crosshead speed (effect of rate on energy to break at 23°C)

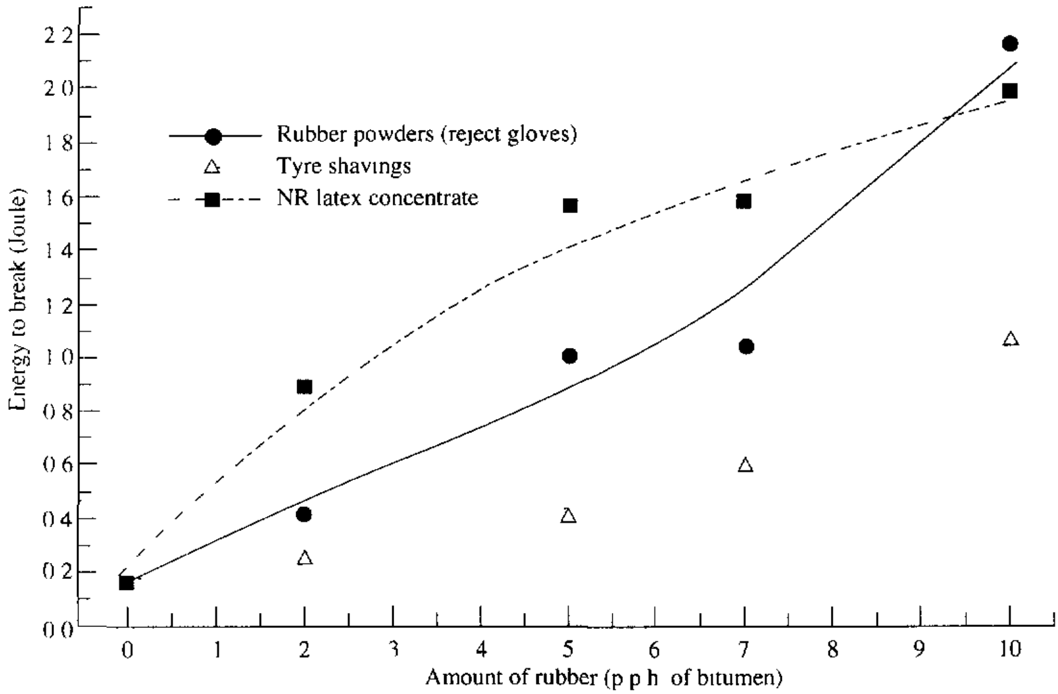

Figure 9 Tenacity versus *amount of rubber (crosshead speed 500 mm/min at 23°C).*

bitumen. Mixes produced using bitumen pre-blended with fine rubber powders clearly show the greatest improvement, causing an increase in the Marshall stability by more than two folds and in the Marshall quotient by nearly three folds compared to the normal unmodified bituminous mix (SX 20). Direct mixing of rubber with bitumen and aggregates (*i.e.* mixing *in situ*) in the pug mill produced rubberised bituminous mixes with an increase in Marshall stability by 1.4 times and in the Marshall quotient by 1.7 times higher than unmodified bituminous mix. Thus, pre-blending of bitumen with rubber is a necessary step in order to produce an efficient rubberised bitumen binder probably due to adequate and efficient rubber dispersions in the bitumen phase.

Indirect tensile modulus test. The indirect tensile modulus test is a quick, non-destructive method of measuring the stiffness of bituminous mixes under dynamic loading conditions to which the material is subjected in practice. In general, the higher the stiffness, the better is its resistance to permanent deformation. *Table 4* shows the results of indirect tensile modulus test. The effectiveness of the pre-blended fine rubber powders is again evident in the indirect tensile modulus test. The elastic modulus of the samples produced using the pre-blended rubberised bitumen is approximately three times greater than that of the unmodified bitumen samples which is in accord with the Marshall quotient results. Thus, the presence of binder modified by preblending with fine rubber powders improved the

TABLE 3. RESULTS OF MARSHALL TEST

Mix	Marshall stability (kN)	Marshall flow (mm)	Marshall quotient (kN/mm)
SX 20	7.62	5.77	1.32
SX 20 + NR latex	13.42	5.44	2.47
SX 20 + glove crumbs	10.90	4.76	2.29
SX 20 + pre-blended	16.12	4.89	3.30

TABLE 4. RESULTS OF INDIRECT TENSILE MODULUS TEST

Mix	Elastic modulus (MPa)
SX 20	2 379
SX 20 + NR latex	2 932
SX 20 + glove crumbs	3 175
SX 20 + Pre-blended glove crumbs	6 579

resistance to permanent deformation by nearly three times than that of unmodified bituminous mixes.

The high elastic modulus of rubberised bituminous mixes has another advantage, *i.e.*, it improves the resistance to rutting. Rutting is accumulation of permanent strain which occurs in two phases. Initially, it is that of densification of the mix, followed by plastic flow of the mix. Rutting usually occurs while climbing lanes and also near roundabouts where vehicles travel at a very low speed. Rutting of road surfaces is hazardous as it disturbs the control of vehicle passing over it. It was reported by the Public Works Department that the addition of natural rubber as an additive to bituminous binder improves the resistance to rutting in the wheel tracking test by a factor of about six compared to unmodified bituminous mix[6].

Indirect tensile fatigue test. The results of indirect tensile fatigue test are shown in *Table 5*. When subjected to repeated indirect tensile loading of 2000 Newton, all samples that had been modified with rubber show higher resistance to fatigue stress. The preblended fine rubber powder samples again performed the best in this fatigue test. While it required more than twice and four times the number of load pulses to reach a permanent strain of 10^{-3} for the directly added latex and rubber powder samples, respectively in comparison to the unmodified bitumen samples (200 pulses); no

TABLE 5 RESULTS OF INDIRECT TENSILE FATIGUE TEST

Mix	Appropriate number of load pulses to reach permanent strain of 10^{-3}
SX 20	200
SX 20 + NR latex	550
SX 20 + glove crumbs	950
SX 20 + Pre-blended glove crumbs	*

*Test terminated after 1000 pulses No permanent strain was recorded by then

permanent strain was induced in the pre-blended rubber powder samples after 1000 pulses Thus the results again shown the better performance of rubberised bituminous mixes than unmodified bituminous mixes in terms of resistance to permanent deformation and fatigue cracking.

Cost effectiveness. Table 6 shows an estimated cost to produce a road pavement section having a length of 200 m, width of 7 m and thickness of 0 05 m base on different types of modified binders and that of unmodified bitumen. The amount of pre-mix required is about 168 metric tons based on 5% binder (by weight). The cost shown in the table includes the labour, processing, construction, raw materials, and overheads, but excludes transportation cost

The total cost to make that section of road pavement using unmodified bitumen is about RM14 280 (RM = Malaysian dollar) or about US$5712 If fine rubber powders reclaimed from reject gloves are used to modify the bitumen, the total cost is about RM16 113 (US$6445 20). An increase in cost of about 13% The cost of rubber powders reclaimed from reject gloves is about RM1.80 per kg

If NR latex concentrate is used to modify the bitumen, the total cost to make a similar road pavement is about RM19 645 (US$7858) An increase in cost of about 35% compared to unmodified bitumen

IF EMA is used to modify the bitumen, the total cost is about RM25 045 (US$10 018) An increase in cost of about 75%

Among the three modifiers, rubber powders reclaimed from reject gloves is the most cost effective. The Marshall quotient of preblended rubberised bitumen is about three times higher than that of unmodified bitumen indicating that the life span of rubberised bitumen pavement is about three times longer than unmodified bitumen pavement[6]. Thus, the effective cost of rubberised bitumen pavement is actually RM5371 (*i e*, RM16 113 – 3), about 2 7 times cheaper in terms of maintenance cost.

DISCUSSIONS

The results discussed above favour the use of rubberised bitumen as an alternative binder instead of unmodified bitumen because of the improvement in the physical properties of both

TABLE 6 ESTIMATED COSTS TO PRODUCE ROAD PAVEMENT SECTION (200 m × 7 m × 0 05 m) USING DIFFERENT TYPES OF MODIFIED BITUMINOUS BINDER

Type of binder	Cost	
	RM	$US
Unmodified bitumen	14 280	5 712
Rubber powders (reject gloves)	16 113	6 445
NR latex concentrate	19 645	7 858
EMA	25 045	10 018

RM = Malaysian ringgit (dollar) RM2 50 = US$1 00

the modified binder and that of the rubberised bituminous mixes Rubberised bitumen has a better temperature susceptibility and less susceptible to temperature changes compared to unmodified bitumen Rubberised bitumen also has a better resistance to deformation and higher tenacity compared to unmodified bitumen Rubberised bituminous mixes are predicted to last at least three times longer than unmodified bituminous mix based on the Marshall quotient and elastic modulus results The question now is the type of rubber most appropriate to use to modify the bitumen Among the rubbers used, it appears that both NR latex concentrate and pre-vulcanised NR latex are the most effective in enhancing both the physical properties of the modified binder and rubberised bituminous mixes However, other relevant factors such as the environment, ease of processing and cost should be considered before deciding the suitability of the rubber

On a laboratory scale it is easy to blend NR latices with bitumen where the experiment can be easily controlled and monitored. However, on a large factory scale, it is not very easy to control and handle the problems associated with foaming, steaming, liberation of ammonia gas and furthermore, if improper stabilisers are used, gellation of the latex may occur due to heat at high temperatures and mechanical agitation. If gellation of latex occurs pre-blending with bitumen is not possible. The liberation of ammonia gas mentioned earlier will also cause pollution to the environment and needs proper effluent treatment to combat the problem

On the other hand, fine rubber powders reclaimed from reject gloves offer a few advantages if they are used as modifier. The advantages with regards to the environmental factors are that it helps to minimise the problems associated with disposing reject gloves and it reduces the problems of pollution associated with burning, burying or disposing discarded gloves into rivers or seas

The advantages concerning processing and cost are that it is easy to blend rubber powders with bitumen without any problems provided that care is taken to choose the correct temperature and speed of mixer, and the cost of rubber powders obtained from reject gloves is cheap, about three times cheaper than NR latex concentrate.

In view of the greater advantages of rubber powders than NR latices in terms of environment friendly, ease of processing and handling and cost of material, rubber powders reclaimed from reject gloves is a very suitable material to modify the bitumen to improve the physical and mechanical properties of the binder and the rubberised bituminous mixes.

CONCLUSION

Addition of rubber into bitumen improves both the physical and mechanical properties of the binder and rubberised bituminous mixes, in particular, in terms of temperature susceptibility and resistance to permanent deformation. Thus, this will lead to an improvement in the service life of the road pavement and hence the overall maintenance cost will be very low.

ACKNOWLEDGEMENT

The author wishes to convey his sincere appreciation to Ir. Hj. Ab. Latif and Ir. Mohd Hizam of IKRAM for useful discussions and comments and also for road trials and testings on bituminous and rubberised bituminous mixes at the Pavement Laboratory of IKRAM.

The technical assistance of Rose Dee of RRIM is also sincerely appreciated. Thanks is also due to Heoe Hock Fie of Asphalt Technology for use of factory facilities to conduct large-scale mixing trials.

Date of receipt: July 1996
Date of acceptance: December 1996

REFERENCES

1. ROUSE M W. (1994) Application of Crumb Rubber Modifiers in Asphaltic Materials. *American Chemical Society Rubber Division Meeting, Chicago, Illinois, April 1994.*

2. MULLINS, L. (1971) *Rubber Development Supplement No 7.*

3. The British Rubber Development Board, London (1950).

4. MAT J. (1989) Ph.D. Thesis, University of Bradford, UK.

5. *Esso Technical Bulletin*, 1990.

6. Public Works Department Research Institute of Malaysia (1993). A Literature Review on the Use and Performance of Bituminous Wearing Course in Malaysia. *Pavement Research Technical Committee Meeting, 1/93(16), 29 April 1993.*