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Flexural Fatigue Characteristics of Asphalt Concrete with Crumb Rubber

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The paper describes an investigation on fatigue of Asphalt Concrete modified by addition of crumb rubber as a part of aggregates. Flexural fatigue tests on Asphalt Concrete and Rubber Modified Asphalt Concrete conducted at 20, 25 and 30°C under constant strain mode indicated that the fatigue life of Rubber Modified Asphalt Concrete is significantly higher than that of the plain Asphalt Concrete. Design charts are presented to show that the pavement with Rubber Modified Asphalt Concrete requires a lower design thickness.

Keywords: asphalt concrete, crumb rubber, fatigue life, design chart

INTRODUCTION

Flexural fatigue cracking of bituminous surfacing of bituminous pavement is a very common phenomenon observed in India because of large number of repetitions of heavy axle loads of commercial vehicle plying on the National Highways. In course of some field investigation (IIT 1993) it was found that the cracking problem was acute particularly for the roads founded on sandy subgrade, even though there was little rutting along the wheel path. The immediate task before the authors was to develop a bituminous material having a high fatigue life without any major change in the manufacturing process.

A review of literature indicated that rubber, either in latex or crumb form, can be used as effective additives to the bituminous mixes to impart greater flexibility to the material and thereby delay the fatigue cracking. There are different ways in which rubber can be incorporated in a bituminous mixture but two methods are found to be popular among the road engineers. The most common method known is the wet process which consists of modifying bitumen at a higher temperature by blending finely ground rubber obtained from discarded tyres so that the properties of the bituminous mixture are modified. In the second method, known as the dry process, discrete pieces of rubber are added to the aggregate during heating process, and after mixing with bitumen and subsequent compaction, the rubber pieces function as elastic aggregates imparting greater flexibility to the bituminous slab. On an examination of the working of

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the hot mix plant in different places of National Highways in Eastern India, it was found that blending of bitumen with the crumb rubber as done in wet process will require changes in the manufacturing system. Addition of the rubber particles directly into the aggregates appeared to be a alternative option. This may also partly solve the environmental problem of disposing automobile tyre in India.

Rolled asphalt wearing course consisting of discrete pieces of tyre rubber laid in 1937 in the London area (*Hatherly and Leaver's 1967*) was generally in good condition even in 1964. Experimental stretches of surface dressing, composed of sand, filler, cutback bitumen and a small amount of rubber powder laid on old bituminous concrete road in The Netherlands from 1935–1938 remained in excellent condition even after being subjected to heavy traffic imposed by the German Armies during Second World War (*Hatherly and Leaver's 1967*).

Thompson (1964) reviewed the results of full scale road experiments using rubberized surfacing materials and reported that addition of 4% rubber considerably reduced the number and severity of cracks, increased the initial holding power between the aggregates and also reduced the tendency to fat up in hot weather under heavy traffic. Crumb rubber modified aggregates were found to show greater resistance to traffic, improved skid resistance, caused less glare and produced less traffic noise (Bathune 1978a; Brown *et. al* 1997b). Central Road Research Institute (CRRI), New Delhi has laid a few test sections with rubber modified bituminous mixture and concluded that it has improved resistance to thermal cracking, rutting, moisture damage and age hardening (Gupta 1997c). Crumb rubber, in the form of mixture of fibres and fines available in plenty at a nominal price in the tyre retreading shops in India, was used in this investigation. Though adequate literature on use of bitumen rubber binder (Daly and Nagulescu 1987a; Roberts and Lytton 1987b; Billiter *et. al.* 1997a, Saboundjian and Raad 1997d, Jagajothi *et. al*, 1999) are available, research work on the application of rubber particle as a part of aggregate in bituminous mixes is limited (Heitzman 1992a; Takallow and Sainton 1992b). Roberts and Lytton (1987b) in their work with crumb rubber suggested that the aggregate gradation should be modified to allow space for the ground rubber considering rubber as an extra aggregate.

The present paper discusses the findings of a laboratory investigation on fatigue behaviour of Rubber Modified Asphalt Concrete (RMAC) in which rubber particles have been incorporated as aggregates. Design charts are included to examine the relative thicknesses of RMAC and conventional Asphalt Concrete (AC) surfacing as per Indian specification (MOST 1995c).

LABORATORY INVESTIGATION

Materials

Bitumen

60/70 penetration grade of bitumen supplied by Indian Oil Corporation, from their *Haldia Refinery* was used for this investigation. Physical properties of the bitumen used are given in Table I.

TABLE I Physical Propertics of Bitumen

S. No. (1)	*Test (2)*	*Test Method (3)*	*Test Result (4)*
1.	Penetration (100 gram, 5 seconds 25°C) (1/10thof mm)	IS 1203–1978	65.0
2.	Softening Point (°C) (Ring & Ball method)	IS 1205–1978	46.5
3.	Ductility at 27°C (5 cm/minute pull)	IS 1208–1978	+100
4.	Specific Gravity	IS 1202–1978	1.0298

Coarse Aggregate, Fine Aggregate and Filler

Coarse and fine aggregates were obtained by crushing of dolerite aggregate procured from *Chandil Quarry* in Bihar. The crushed stone was sieved into various fractions after washing and drying. Ordinary Portland Cement (OPC) was used as filler. The gradation adopted was as specified by Ministry of Surface Transport for AC (MOST 1995c) and is given in Figure-1. Specific gravities of aggregate and filler are given in Table-II.

Rubber

Rubber in crumb form obtained as tyre waste procured from tyre retreading shops was used in this investigation. The specific gravity was found to be 1.065. The gradation and the dimension of crumb rubber used in the investigation are given in Table-III(a) and Table-III(b), respectively. About 40% of the rubber was in fiber form retained on 1.18 mm sieve and the remaining was in particulate form ranging from 1.18 mm to 0.15 mm.

TABLE II Specific Gravity of Aggregate and Filler

Type of Aggregate (1)	*Test Method (2)*	*Test Result (3)*
Coarse Aggregate	IS 2386(Part III)-1963	2.671
Fine Aggregate	IS 2386(Part III)-1963	2.677
Filler	IS 4031-1968	2.979

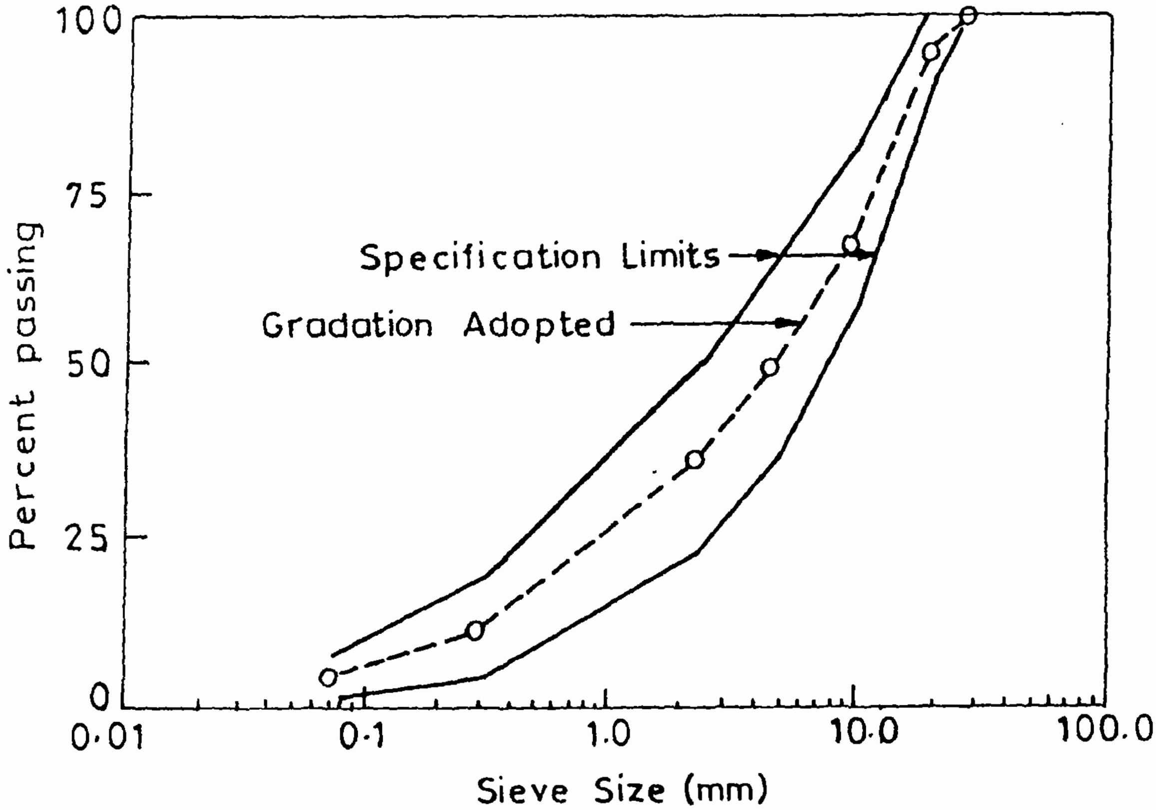


FIGURE 1 Gradation of Aggregate Adopted

TABLE IIIa Gradation of Crumb Rubber

Sieve Size Opening mm (1)	*Percent by Weight Passing (2)*	*Gradation Adopted (3)*
4.75	100	100.0
2.36	87–92	89.5
1.18	60–64	62.0
0.06	34–36	35.0
0.03	9–10	9.5
0.015	0	0.0

TABLE IIIb Average Length of Crumb Rubber

Passing Sieve Opening (mm) (1)	*Retained on Sieve Opening (mm) (2)*	*Length of Rubber (mm)*	
		Mean (3)	*Std. Dev. (4)*
4.75	2.36	15.09	5.414
2.36	1.18	8.47	3.130
1.18	0.06	3.94	3.011
0.06	0.03	Powder Form	–
0.03	0.015	"	–

Cohere, Std. Dev. = Standard Deviation

Bituminous Mix

Asphalt Concrete samples, both plain and rubberized with 1.5% and 3.0% rubber by weight of aggregate were tested for Marshall requirement with 75 blow compaction on each face. The results of Marshall tests are presented in Table-IV. It is seen that OBC for AC is 5.17%, whereas when 3% rubber by weight of dry aggregate particles is used, OBC obtained by averaging of bitumen contents for maximum bulk density and air void content, becomes 6.47%. Higher bitumen content for RMAC is due to the fact that the specific gravity of rubber particles is low and has much larger surface area. It was further found that air void for 3% rubber content becomes 2.2% at OBC which is rather low, hence bitumen content for casting beams for fatigue tests was reduced to 6% at which the sample satisfied all the Marshall mix design criteria laid down by MOST (1995b).

TABLE IV Results of Marshall Tests based on 75 Blows on Each Face

Description (1)	*Asphalt Concrete (2)*	*Rubber Modified Asphalt Concrete containing crumb rubber*	
		1.5 percent (3)	*3.0 percent (4)*
Optimum Asphalt content as percentage weight of total mix (percent)	5.17	5.54	6.47
Stability (kN)	10.7	9.8	8.1
Flow (mm)	2.7	3.8	6.0
Air Voids (percent)	3.65	2.7	2.2
Bulk Density (kg/m^3)	2387	2358	2315
Voids in Mineral Aggregate (VMA, percent)	15.7	15.4	15.9
Voids in Mineral Aggregate filled with Bitumen (VFB, percent)	75.5	81.0	84.5

TABLE V Propertics of Beam Specimen

Mix type (1)	*Temperature of testing (°C) (2)*	*No. of samples tested (3)*	*Bitumen content (%) (4)*	*Bulk density kg/m^3*		*Air Voids (%)*	
				mean (5)	*Std. Dev. (6)*	*mean (7)*	*Std. Dev. (8)*
AC	20	15	5.17				
	25	15	5.17	2364	19	4.72	0.77
	30	15	5.17				
RMAC	20	15	6.00				
	25	15	6.00	2246	41	4.86	1.75
	30	15	6.00				

Preparation of Test Specimen

The aggregates along with crumb rubber were taken in a mixing bowl and heated to a temperature of 150–160°C. Appropriate quantity of 60/70 penetration grade bitumen by weight of dry aggregates heated separately to about 140°C was added to the aggregates. It was mixed for about five minutes using a spatula till the aggregates were thoroughly coated with bitumen. The mix was then transferred to a pre-heated mould of size 77 × 77 × 380 mm^3 in two layers, each layer being tamped 50 times by a 12 mm diameter rod. About 30 kN load was applied to the specimen by a hydraulic jack through small rectangular compaction plunger of dimension 75 mm × 125 mm. Upon unloading, the plunger was shifted sideways so as to have a overlap 2/3rd of the previously compacted mixture and load was applied again. The mixture was compacted using this approach. Because of the kneading action, the achieved density was higher than 98% of Marshall compaction in most cases. The physical properties of the beam specimens are summarized in Table-V. The specimens were immersed in a water bath, for about 60 minutes to bring them to the test temperature in a time prior to the testing. The temperature of the test room was maintained by a air-conditioner.

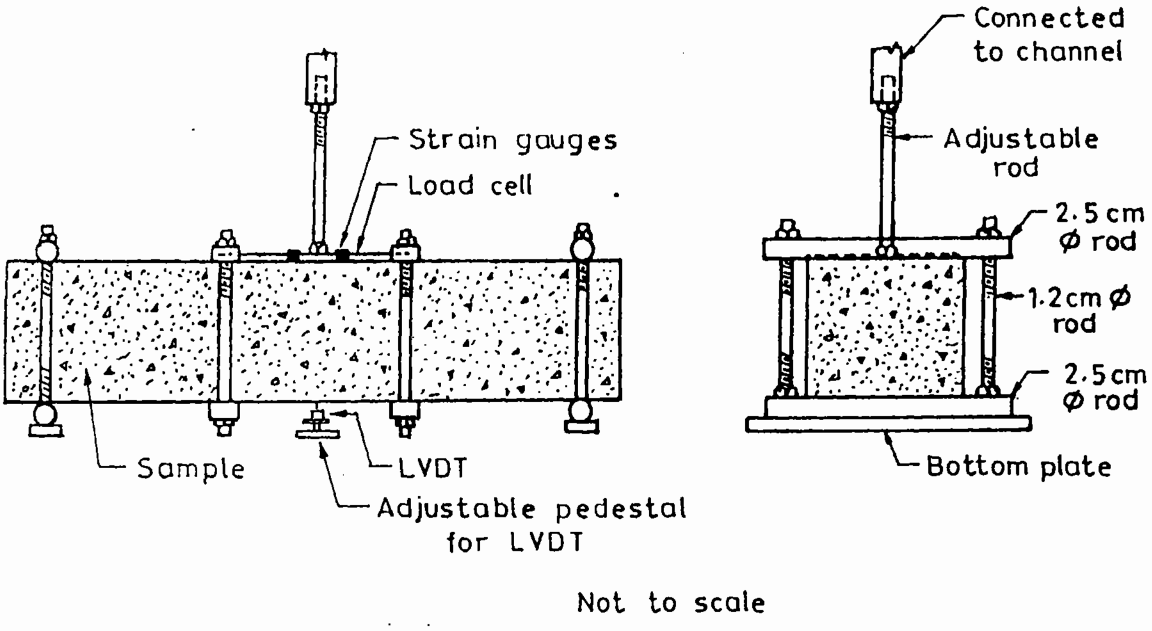


FIGURE 2 Longitudinal and Cross-Sectional View of Test Specimen Under Cyclic Load

Experimental Set-Up

Figure 2 shows the longitudinal and cross-sectional view of the test specimen under cyclic load used for the fatigue test. The apparatus (Pandey 1996a) consists of a speed controlled DC Motor connected to a cam by which the rotational motion of the motor results in application of repeated constant displacement of the beam specimen. The displacement is applied to the beam specimen through a set of levers.

A Load Cell was mounted on top of the loading plate to measure the load applied on the specimen and an LVDT was placed just below the specimen to record the deflection. The speed of the motor was adjusted to 500 revolutions per minute (rpm) which corresponds to a loading on the pavement due to a vehicle moving at a speed of 50–60 kilometres per hour (Shell 1978b).

Fatigue Test Method

The beam was tested under fourth point loading, as shown in Figure 3 so that the failure is localized in the central portion of the beam where the bending moment is constant. The test was done under controlled strain mode and the failure of the specimen was defined as the number of cycles required until the amplitude of the applied load for a particular value of central deflection reduced to half of the initial value.

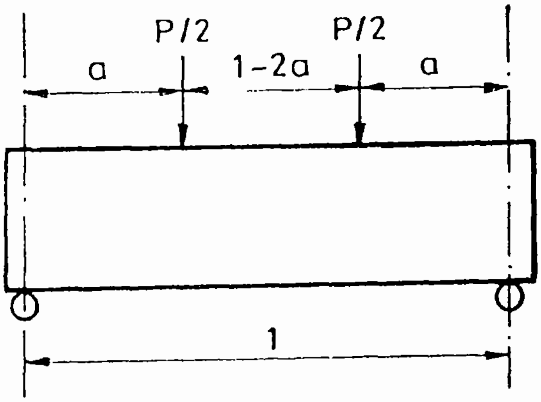


FIGURE 3 Fourth Point Loading

RESULTS OF THE INVESTIGATION

Results of the fatigue test on AC and RMAC are given in Figures 4 and 5 at different temperatures and elastic moduli respectively. The equations of the fatigue lines the corresponding regression coefficients are given in Table-VI. The elastic moduli (E) values at a different temperatures are summarized in Table-VII. The mean values of air voids if AC and RMAC samples were found as 4.72% and 4.86% respectively.

TABLE VI Results of Fatigue Tests

S. No.	*Temperature of Testing (°C)*	$N = k\,(1/\varepsilon_t)^n$ *k*	*n*	*Co-efficient of determination (r^2)*
1		Asphalt Concrete		
	(a) 20	1.8398×10^{-9}	3.358	0.90
	(b) 25	6.7109×10^{-11}	3.738	0.86
	(c) 30	4.9771×10^{-13}	4.596	0.53
2.		Rubber Modified Asphalt Concrete		
	(a) 20	6.1231×10^{-8}	3.223	0.88
	(b) 25	1.6451×10^{-11}	4.450	0.82
	(c) 30	4.4526×10^{-8}	3.587	0.90

where, ε_t = tensile strain; k, n = regression constants

TABLE VII Elastic Modulus Values at Different Temperatures

Mix type (1)	*Temperature (°C) (2)*	*No. of samples tested (3)*	*Elastic modulus, E, MPa*	
			value (4)	*Std. Dev. (5)*
AC	20	21	4296	1794
AC	25	23	3885	1323
AC	30	30	1670	844
RMAC	20	30	1753	873
RMAC	25	35	1198	934
RMAC	30	39	336	145

Findings of Fatigue Test

The results showed that the fatigue life of the RMAC specimens for equal tensile strain was much higher than that of the AC samples tested at the same temperature. As observed in Figures 4(a), 4(b) and 4(c), for a tensile strain (ε_t) of 3×10^{-3}, the corresponding fatigue lives of AC and RMAC are 1000 and 10,000 repetitions at 20°C, 1000 and 80,000 repetitions at 25°C, and 6,500 and 2,50,000 repetitions at 30°C temperature respectively. Thus it was seen that the lives increase by factors of 10, 80 and 40 at 20°, 25° and 30°C, respectively. The investigation conclusively proves that RMAC is expected to have much longer fatigue life than the conventional AC.

Figures. 5(a) and 5(b) present the fatigue curves at different temperatures for AC and RMAC respectively, which could be used in pavement design after applying appropriate shift factor. Figure 6 present the variation of elastic moduli versus temperature for both AC and RMAC.

DESIGN OF PAVEMENT

Fatigue Equation

The generalized fatigue equation can be represented as follows:

$$N_f = k_1(1/E)^{k_2}(1/\varepsilon_t)^{k_3}$$

where,

N_f = number of repetitions causing fatigue failure

E = elastic modulus of the bituminous layer

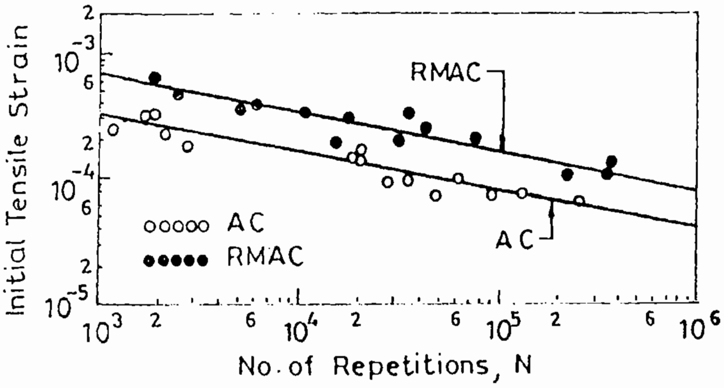
ε_t = horizontal tensile strain at the bottom of the bituminous layer and k_1, k_2 and k_3 are regression coefficients

The overall regression coefficients for AC and RMAC used in pavement design are presented in Table-VIII. The coefficient k_1 has been adjusted by multiplying the laboratory determined coefficient with a shift factor obtained from the field performance data of 120 number of AC road sections collected through R-6 (1995a) and R-19 (1994b) research schemes of Ministry of Surface Transport (Das 1998).

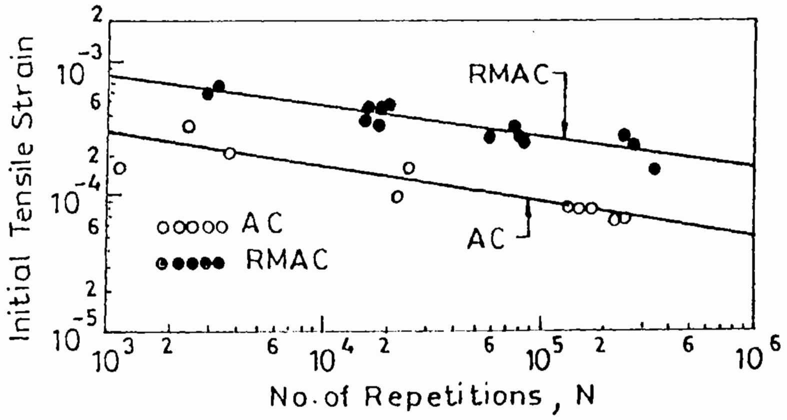
The average annual pavement temperature was assumed as 35°C and the bitumen of 80/100 grade was used for all the sections. The fourth power equivalency factor was used for computation of the cumulative equivalent standard axle load repetitions from the analysis of axle load data and the traffic count for National Highways in India (1995a). The pavement performance data was collected for about five years and the maximum number of repetitions of equivalent single axle load was nearly 50 million. A pavement with 25% of surface cracks was deemed to have failed in fatigue. Idealizing a pavement as a three layered elastic system consisting of AC, granular base and the subgrade, appropriate elastic moduli were assigned to each of the layers. For computation of elastic modulus of subgrade it was assumed as ten times the CBR value (Pandey and Naidu 1994a) and for granular layer Shell's (1978b) equation was used. The number of standard axle load repetitions for 25% cracking of pavement were computed by the multi-layer pavement analysis program **FPAVE** developed by the authors (Das 1998). Since performance data-base of RMAC surfacing for Indian conditions of traffic and environment is not available, the shift factor for RMAC fatigue curve has been assumed to be the same as that adopted for AC. The shift factor for RMAC road stretches can be determined precisely once performance data based on Indian traffic and environmental conditions is made available.

Rutting Equation

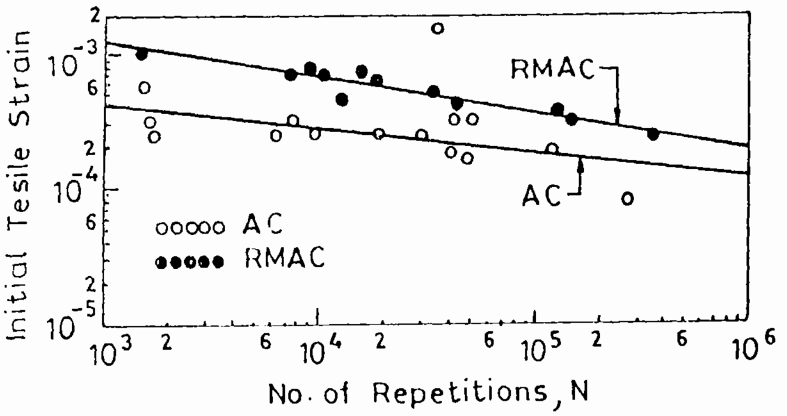
A total of 86 sections on National Highways were considered for developing a rutting criterion. The rut



(a) Fatigue Test at 20°C

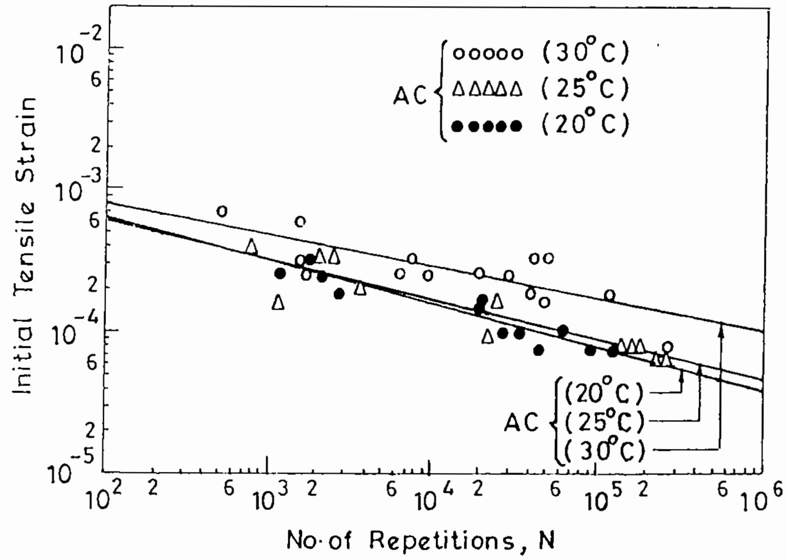


(b) Fatigue Test at 25°C

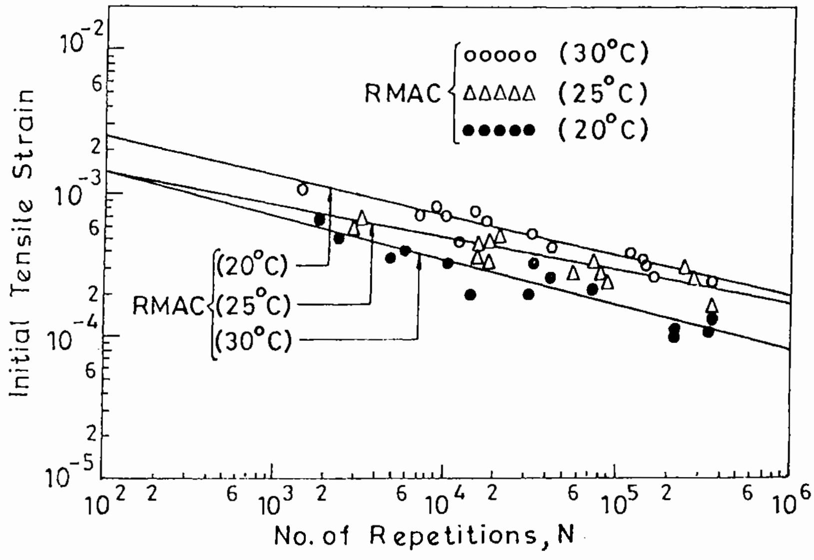


(c) Fatigue Test at 30°C

FIGURE 4 Fatigue Test Results: Initial Tensile Strain vs. No. of Repetitions (at different temperatures)



(a) Asphalt Concrete



(b) Rubberised Asphalt Concrete

FIGURE 5 Fatigue Test Results: Initial Tensile Strain vs. No. of Repetitions (at different elastic moduli)

depth along the wheel path was measured with a 3 metre straight edge at regular intervals in both the directions of traffic with allowable rut depth set at 20 mm as suggested by practising engineers and road users (Das 1998). The pavements consisting of bituminous surfacings, granular base and the subgrade was analyzed as three layered elastic systems and vertical subgrade strain (ε_z) was computed for all the

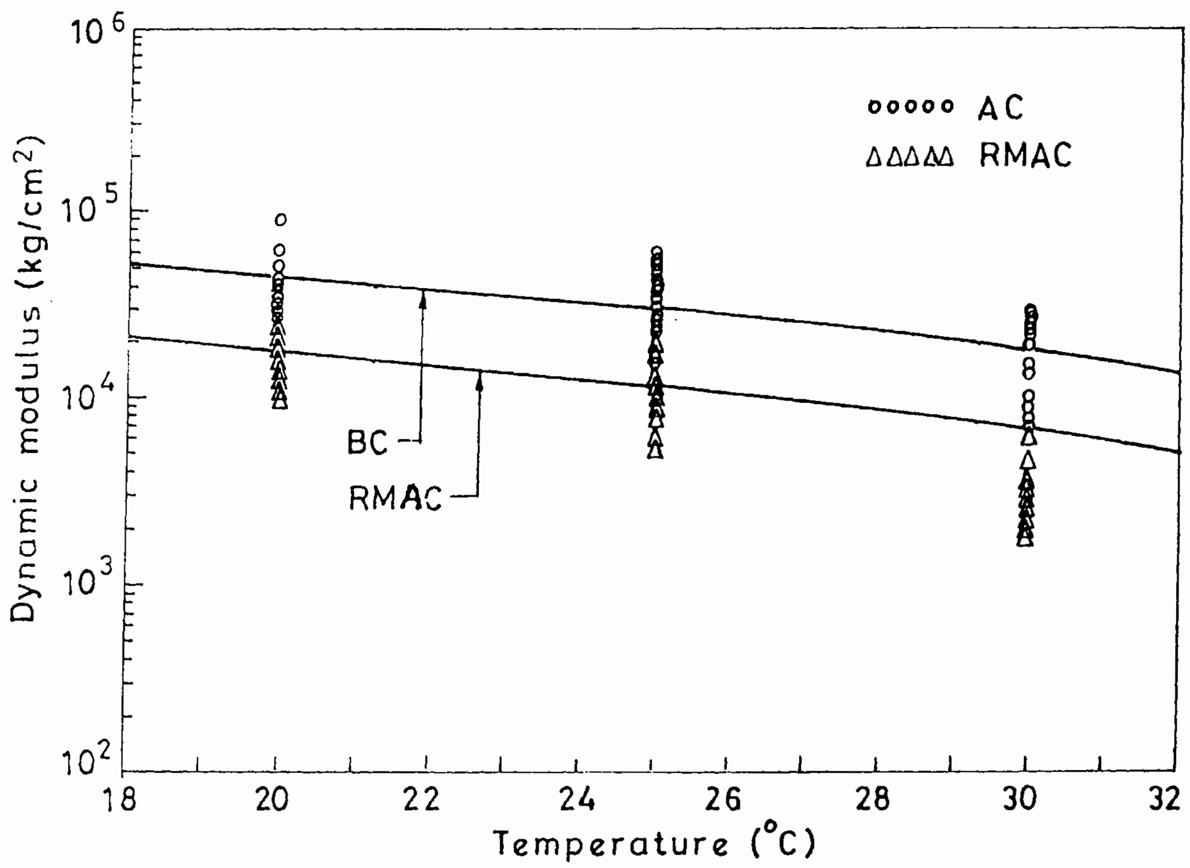


FIGURE 6 Elastic Modulus Vs. Temperature

pavement sections. The number of repetitions of standard axle load (N_r) was computed for the sections when the rutting reached a value of 20 mm. The following rutting criterion of 84% reliability was developed by keeping 84% of the data points above the line (Das 1998).

$$N_r = 2.26 \times 10^{-2}(1/\varepsilon_z)^{4.337}$$

N_r = number of repetitions causing rutting failure
ε_z = vertical subgrade strain

A computer program **IITPAVE** was developed for design of bituminous pavements with granular bases using the program **FPAVE** as subroutine (Das 1998). ε_t and ε_z for a standard axle load were calculated at the critical points of a bituminous pavement structure and the allowable strains were obtained from the fatigue and rutting criteria for a given design period. *Golden Search Optimization* technique was used for arriving the design thickness of the bituminous layer within few iterations (Das 1998). Pavement design charts are prepared by drawing the recommended design thickness governed either by fatigue or by rutting equation.

Design Charts

Thickness design charts in Figures-7(a) to (d) were developed for pavements having both AC and RMAC surfacing for 20, 50, 100, 150 and 200 million standard axle (msa) repetitions. The subgrades selected have a elastic moduli of 20MPa and 65MPa respectively. Shell's (1978b) criterion was adopted for eval-

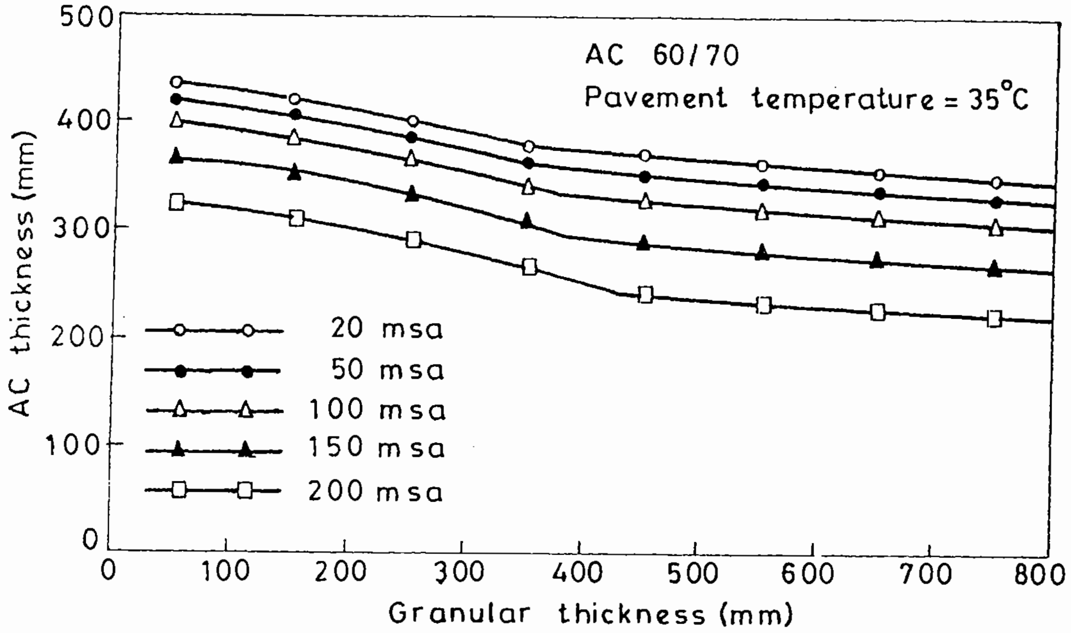


FIGURE 7(a) Bituminous Pavement Design Chart with Granular Base, Subgrade Modulus = 20 MPa

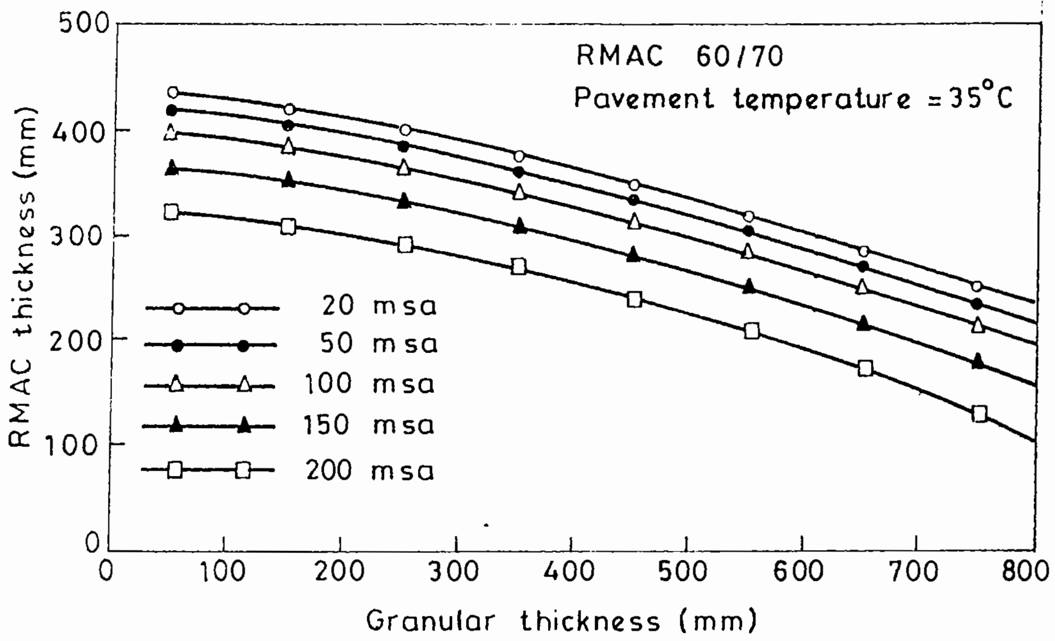


FIGURE 7(b) Bituminous Pavement Design Chart with Granular Base, Subgrade Modulus = 20 MPa

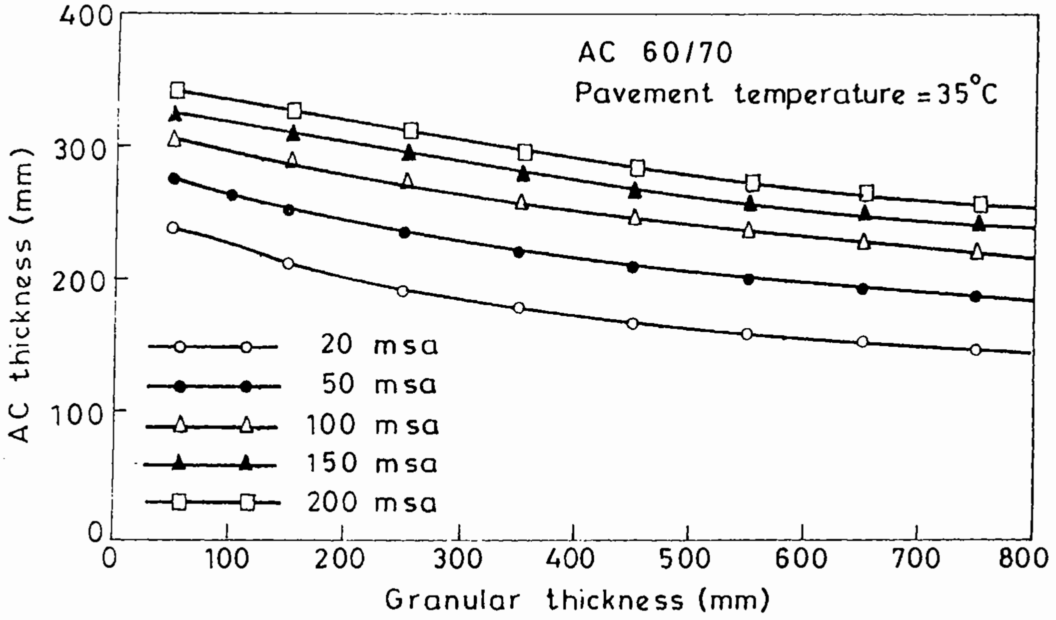


FIGURE 7(c) Bituminous Pavement Design Chart with Granular Base, Subgrade Modulus = 65 MPa

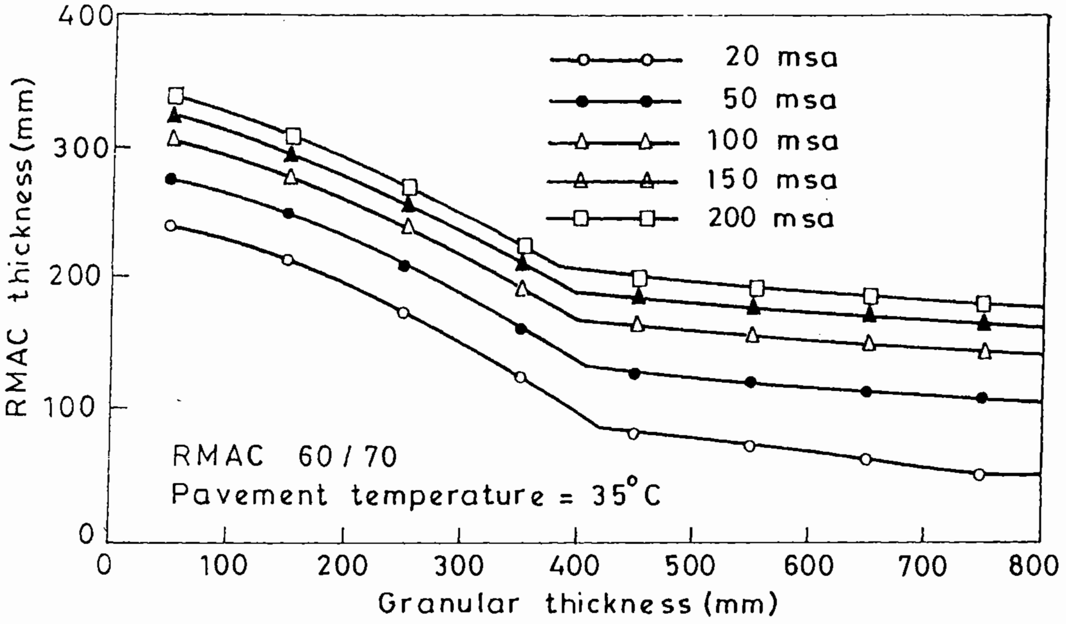


FIGURE 7(d) Bituminous Pavement Design Chart with Granular Base, Subgrade Modulus = 65 MPa uation of elastic modulus of unbound granular layer. Average annual pavement temperature was assumed to be 35°C. Poisson's ratios (μ) of the bituminous layer, granular layer and subgrade were taken as 0.5, 0.4 and 0.4, respectively.

It is seen that for higher thickness of unbound granular materials, thicknesses required for RMAC are much lower than AC. For subgrade of 20 MPa thicknesses of RMAC as well as AC surfacing are almost equal for low values of granular thicknesses. From Figures 7 (a) and (b) thickness of AC and RMAC surfacings for 700 mm granular bases are found as 230 mm and 160 mm respectively for a lower subgrade modulus (20 MPa), whereas while for a strong subgrade (65MPa, Figures 7(c) and (d)) thickness of AC and RMAC are obtained as 170 mm and 90 mm respectively for 400 mm granular layer. Practical thickness of granular layers consisting of bases and subbases and cracked bituminous layers are generally more than 500 mm for heavy traffic applications and RMAC surfacing may provide a cost effective pavement.

CONCLUSION

From the current investigation it was seen that the addition of crumb rubber in crumb form obtained from waste tyres in the form of fine aggregates increased the fatigue life of the bituminous material substantially. The mix has the required minimum Marshall stability and it would be able to withstand repeated load due to heavy traffic better than AC. The thickness of the RMAC mix for a given traffic is substantially lower than the corresponding AC mix for practical thickness of granular bases.

NOTATIONS

The following symbols are used in this paper:

AC = Asphalt Concrete
E = Elastic modulus of the bituminous mix
LVDT = Linear Variable Differential Transducer
RMAC = Rubber Modified Asphalt Concrete
r^2 = Co-efficient of Determination
Std. Dev. = Standard Deviation
ε_t = tensile strain
ε_z = vertical subgrade strain

TABLE VIII Fatigue Regression Co-efficients

Mix type (1)	*No. of samples tested(2)*	$N = k_1 (1/E)^{k2} (1/e_t)^{k3}$			*Coefficient of Determination (r^2)(6)*
		k_1 (3)	*k_2 (4)*	*k_3 (5)*	
AC	60	5.975×10^{-5}	1.4747	3.565	0.74
RMAC	75	5.799×10^{-3}	1.1517	2.924	0.93

k_1, k_2 and k_3 are the regression co-efficients

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