

# Exploring the Properties of Recycled Tyre Rubber for Flexible Asphalt Pavement

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**Abstract:** In consideration of the issue related to the poor performance of asphalt pavements against climatic stresses and the need to contribute to the solution of the ever-increasing environmental hazards, the study paved the way for the recognition of using waste tyre as an asphalt binder modifier for pavement construction to settle the rising issue on waste disposal, while also improving the pavement properties.

A series of experiments were conducted using different levels of recycled tyre rubber (RTR) substituted in asphalt binder. Marshall Stability and Marshall Immersion test were selected as basis to evaluate the properties. The results of experiments conducted on Marshall Mix samples demonstrated that stability of the pavements increased in a quadratic fashion with increasing fraction of RTR, and were found to be maximum at 10% rubber in asphalt mix, contributing an average enhancement of approximately 35% as compared to the conventional pavements. Furthermore, retained stability of samples was found to increase with increasing ratio of rubber substituted, making it a suitable candidate for modification in highly humid and rainy areas.

**Keywords:** Recycle tyre rubber (RTR), polymer modified asphalt, asphalt pavement.

## 1. INTRODUCTION

The road which utilizes pure asphalt as binder turns brittle after time, once asphalt is oxidized under the action of environment and changes from black to grey colour. Such brittle behaviour leads to brittle fracture in pavements in the form of cracks.

Therefore, by substituting recycled tyre rubber (RTR) in pure asphalt binder, we can enhance the durability, performance, flexibility and skid resistance of asphalt pavement while also reducing the traffic noise by utilizing the elastic behaviour of rubber [1, 2]. Thus, with improved properties, the maintenance cost and the life cycle cost will also be reduced.

Different researches on Rubber Modified Asphalt (RMA) pavements have been conducted by various Departments of Transportation (DOTS) of US states and across the globe. Florida DOT constructed several prototypes of asphalt pavement with Crumb rubber Modifier (CRM) using wet processes in 1989. The results reported that the incorporating CRM increases the asphalt film thickness, resiliency of binder, shear strength, and viscosity [3].

Troy *et al.* [4] also conducted a research on Rubber Modified Asphalt (RMA) pavements. The research employed the Hveem procedure to form the mix design, while CRM binder was evaluated using the

Superpave binder testing protocols. They concluded that the conventional sample geometry in Superpave binder test protocols cannot be used to test the CRM binders and that the Hveem compaction is inadequate for mixtures containing CRM binders.

Presti *et al.* [5] reported that although Tyre Rubber Modified Binders (TRMB), produced through McDonald wet process, have been proven to provide numerous benefits to pavements, the technology is still struggling mainly because of their poor stability during high temperatures storage, which leads to high initial costs in modifying existing asphalt plants. The authors believe that "terminal blends" or "field-blends", are one of the keys to overcome the storage cost.

Singh [6] conducted a research on various rheological and chemical properties of RMA binder. The research concluded that increasing the Styrene Butadiene Styrene (SBS) content in asphalt results in increased polymer swelling, which in turn produces increase in asphaltenes and reduction in maltene content resulting in harder and viscous matrix. Furthermore, rubber modification leads to decrease in penetration value, and increase in softening point and rutting parameter of asphalt binder.

Way G. and Hunt in their studies reported that CRM, when used in normal Hot Mix Asphalt (HMA) mixtures, has significantly improved the performance of asphalt binder. The effect of CRM has been roughly equivalent to the addition of polymer to conventional asphalt cement [7, 8].

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According to survey, there is an increasing rate of adopting rubber as a modifier for roads construction in different parts of the world [10]. Since waste tyre has been used in many other countries as modifier, most researchers focus on the qualitative analysis of Rubber Modified Asphalt (RMA) binder [11], however, not much work is available on the quantitative behaviour of RMA pavements.

The aim of this study is:

1. To perform a quantitative analysis on the major properties of asphalt pavements for increasing rubber fraction in asphalt binder.
2. To substitute pure asphalt with relatively cheap waste tyres, thus decreasing the overall raw material capital investment significantly, while also enhancing the properties of pavements

## 2. EXPERIMENTATION

### 2.1. Materials

There are three key raw materials that are required to prepare specimen, namely, pavement grade asphalt, fine powder of recycled car tyres of particle size < 0.1 mm (passed from sieve no. 30), aggregates of different sizes and filler (soil).

The samples were prepared according to the Tables 1-4.

### 2.2. Sample Preparation

The experimental program comprises of the following steps;

- i) Marshall specimens were made according to the standard procedure as prescribed by AASHTO T 245. In the first step 1200 gm. mixture of aggregate and filler was heated up to 160°C.
- ii) For incorporating RTR into asphalt, the Wet Process Technology was adapted. In this process, asphalt was heated in a vessel at 160°C, till it melts to viscous liquid. Crumb RTR was then added to the melt and was mixed vigorously. The mixture was then heated to 160°C for 60 minutes with intermittent stirring.

The interaction between rubber and asphalt is carried out in two simultaneous steps: partial digestion of the rubber into the bitumen on one hand and, on the other, adsorption of the aromatic oils available in this latter within the polymeric chains that are the main components of the rubber, both natural and synthetic, contained in the RTR. The absorption of aromatic oils from the bitumen into the rubber's polymer chains causes the rubber to swell and soften [12]. Rubber particles are swollen by the absorption of the bitumen oily phase at high temperatures (160–200°C) into the polymer chains, which are the key components of the RTR-MB to form a gel-like material.

Then the heated mixture of asphalt binder and aggregate were thoroughly mixed in an oven at a temperature of 160°C for 2 hours to provide better surface adhesion before compaction.

The rammer and compaction mould assembly was preheated at 145°C. The pre-heated mould assembly was positioned on the mould holder of the Marshall Mix compaction machine. The mixture was poured into the mould in three layers. Each layer was spaded using

**Table 1: Material Weight Specification for 0% Rubber in Asphalt Marshall Samples**

Material (grams)	Asphalt Content (%)						
	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Asphalt	36	42	48	54	60	66	72
Rubber	0	0	0	0	0	0	0

**Table 2: Material Weight Specifications for 10% Rubber in Asphalt Marshall Samples**

Material (grams)	Asphalt Content (%)						
	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Asphalt	32.4	37.8	43.2	48.6	54	59.4	64.8
Rubber	3.6	4.2	4.8	5.4	6	6.6	7.2

**Table 3: Material Weight Specification for 20% Rubber in Asphalt Marshall Samples**

Material (grams)	Asphalt Content (%)						
	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Asphalt	28.8	33.6	38.4	43.2	48	52.8	57.6
Rubber	7.2	8.4	9.6	10.8	12	13.2	14.4

**Table 4: Material Weight Specification for 30% Rubber in Asphalt Marshall Samples**

Material (grams)	Asphalt Content (%)						
	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Asphalt	25.2	29.4	33.6	37.8	42	46.2	50.4
Rubber	10.8	12.6	14.4	16.2	18	19.8	21.6

tamping rod, 15 times around the outer perimeter and 10 times at the interior portion of the mix. Greased paper disk was placed above and below the mix in the mould, to prevent undesirable adhesion. Once the heated mixture was filled in mould assembly 75 blows were applied using compaction hammer having a free fall of 18", for heavy traffic specification. After compaction, the collar was removed. The mould was then reversed and reassembled and 75 blows were applied on the reverse side. The base plate was removed after compaction. Turn the moulds over and reassemble the mould with the base plate and collar. Apply the same number of compaction blows as on the reverse side. The sample is taken out of the mould after few minutes using sample extractor. The specimen was then allowed to cool for 24 hours at room temperature.

### 2.3. Material Weight Specification

In all samples 1200 grams of aggregate is added.

## 3. RESULT AND DISCUSSION

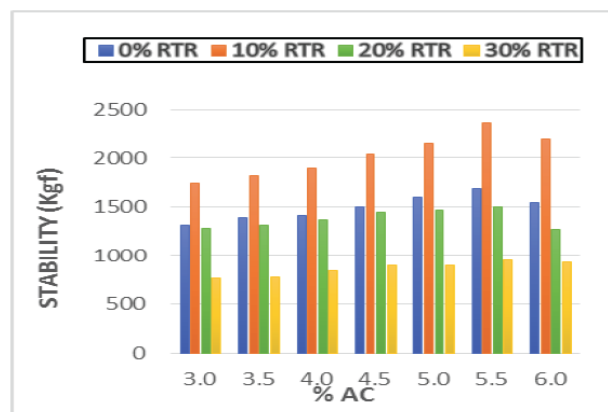
The Marshall test method was used to carried out the tests of compacted samples. All the samples were subjected to the following tests:

### 4.1. Effect on Flow & Stability

For Flow and stability test, the specimen was immersed in a water bath maintained at a temperature of 60°C for 30 minutes. The sample was then placed in the Marshall Stability testing machine, and loaded at a constant rate of deformation of 5 mm per minute until failure. The Marshall Stability of a test specimen is the maximum load required to produce failure when the specimen is pre-heated to the specified temperature.

Two dials were located on the Marshall Test machine that showed the value of maximum load born and the vertical deformation of the specimen at that maximum load.

The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds.

**Figure 1: Effect on Stability.**

From the bar chart, it can be observed that stability of the sample is maximum when 10% of AC is substituted with RTR, with an average increase of as much as 35%, as better compactions are possible with increased rubber content. However, upon further substitution the stability of specimen starts to decrease, which is slightly lower than the stability of pure asphalt binder at 20% RTR substitution but plummets once the substitution of 30% RTR is done. This is because rubber itself does not have any binding ability and the binding properties of binder come solely from the contribution of asphalt. Therefore, substituting higher proportions of rubber in asphalt binder reduces the overall binding ability of binder.

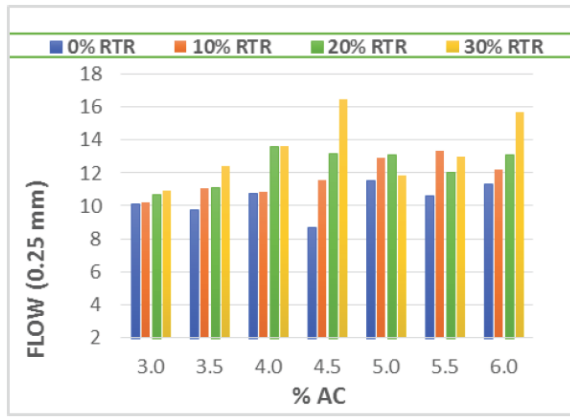


Figure 2: Effect on Flow.

It can be observed that flow of the specimen increases with increasing RTR content in asphalt binder. This is because increasing RTR content increases the amount of air voids in the sample, and also decreases the adhesion between aggregates in the sample, due to increased viscosity and decreased binding ability of binder.

4.2. Effect on Density

The bulk density of the sample was determined by weighting the sample in air and in water. The specific gravity Gbcm of the specimen is given by:

$$G_{bcm} = \frac{W_a}{W_a - W_w}$$

where,

W<sub>a</sub> = weight of sample in air (g)

W<sub>w</sub> = weight of sample in water (g)

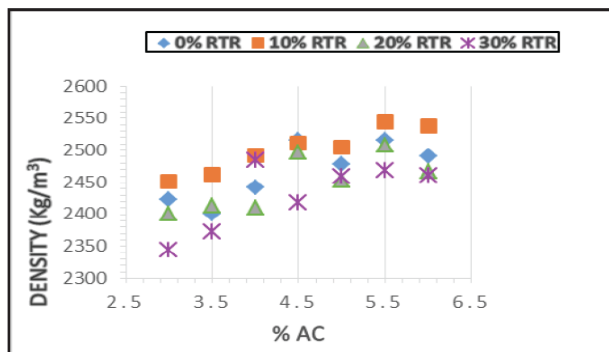


Figure 3: Effect on Density.

From graph, it can be observed that density followed a similar pattern to that of stability, i.e. density of specimen is maximum at 10% RTR in asphalt binder while it starts to decrease once RTR fraction is above 20% in total binder, however the variation in density is

not as much as that observed for stability. This is because RTR is substituted with asphalt in total binder, which kept the total weight of sample constant, and also the density difference between asphalt and RTR is not too significant.

Moreover, density is found to be maximum at around 5.5% AC. This is due to the fact that increasing binder content decreases the amount of air voids present in the specimen, which in turns increases the overall density.

4.3. Effect on Moisture Susceptibility

Water retained stability for moisture susceptibility was calculated using Marshall Immersion test. Marshall specimens were kept immersed in water maintained at 60°C for 24 hours. After that, the samples were taken out and Marshall Stability test were performed on them. The results were then compared with the results obtained for normal Marshall Stability test. The retained stability index (expressed in %) then could be calculated by dividing the strength obtained by the specimen immersed n water at 60°C by the strength obtained by the dry one.

$$\text{Water Retained Stability} = \frac{S_2}{S_1} \times 100$$

Where, S<sub>1</sub> = Strength of dry sample

S<sub>2</sub> = Strength obtained after immersion

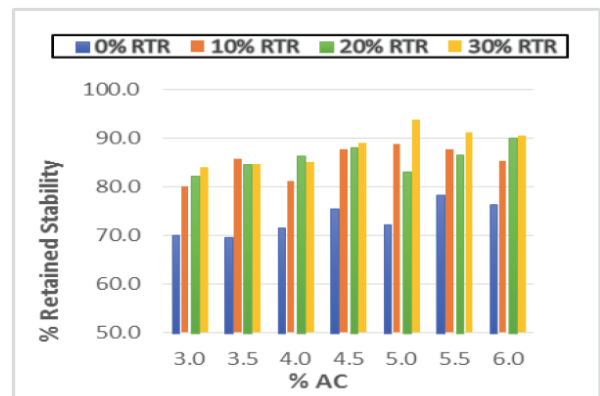


Figure 4: Effect on moisture Susceptibility.

According to the findings, it can be observed that upon substitution of RTR in binder, the retained stability of samples increases substantially. This is because asphalt is more susceptible to moisture damage as compared to rubber.

Furthermore, although the Immersed Stability of 10% RTR substituted in binder is maximum among the

rest of the fractions the overall retained stability of specimens increases with increase in RTR fraction in asphalt binder. Since rubber, being a polymer, is more resistant to water and is also less susceptible to temperature as compared to asphalt, it assists the specimen to retain its stability even after immersion.

## CONCLUSION

The effects on various properties of asphalt pavements upon substitution of recycled tyre rubber in asphalt binder were successfully evaluated. Based on the results obtained in the research, the following conclusions were derived:

- i) Greater stability of pavements was achieved upon modification of asphalt up to a substitution of 10% of RTR in binder, where the average stability values were witnessed to increase to approximately 35%. Further substitutions resulted in a decrease in stability and were found to be infeasible.
- ii) Flow on compression increased as greater fractions of RTR were incorporated, however, the values obtained remained within the specified range as prescribed by the standards.
- iii) The resistance to moisture damage improved substantially as the RTR content in binder increased. This makes RTR a worthy candidate for modification of pavements, especially in the rainy areas.

This process is suitable and efficient for field asphalt blend which is a common practice in Pakistan. If it is needed to be used as a terminal blend (manufacture at a distant place) then it can be stored in specially designed vessels provided with stirrers and intermittent heating, however, the process is neither suitable nor efficient for prolonged storage as asphalt may degrade and swelling of rubber with asphalt components with time may cause deterioration of properties as rubber would be digested by asphalt.

The overall raw material capital cost was reduced as cheap waste rubber was substituted with relatively expensive asphalt.

Incorporation of RTR in asphalt would also reduce the harmful impact of waste tires on environment.

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