Pak. j. sci. ind. res. Ser. A: phys. sci. 2022 **65A**(3) 271-281

Effect of Waste Crumb Rubber on Selected Properties of Bitumen

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(received March 15, 2021; revised November 2, 2021; accepted November 23, 2021)

Abstract. In recent years the road surface conditions in Pakistan have been getting worse day by day, like rutting, thermal cracking and increased resistance to many forms of traffic-induced stress can be seen. There should be more concern about durability. Polymer modification of bitumen has become the optimal technique in designing better performance of pavements. Working with polymer modified bitumen is an excellent solution to this and a lot of work with various polymers has either been done or in the pipeline. The advantage of polymer modification of bitumen is that offers enhancements in performance and durability, qualifying of pavement distress and reduced life cycle costs when it is differentiated to unmodified bitumen or hot mix bitumen surface dressings.This study considers the sustainable pavement method when recycled rubber is taken from window fittings in crumbed form is mixed with a hot bitumen mixture. The main objective was to inspect the impact of adding recycled crumbed rubber to the bitumen mixture. The dry process method was used in which four different crumb rubber contents (1%, 3%, 5% and 7% wt.) in the asphalt mixture were investigated. The working temperatures to mix the crumbed rubber in the hot bitumen were around 180 °C-190 °C. Considering the Marshall stability esteem and the volumetric properties, acomparative study was done amongst the unmodified bituminous mixture and whole bituminous concrete mixtures. The results introduced that crumb rubber is an added substance in the asphalt mixture, as all the results are inside the normal pre requisites. The crumb rubber addition to the asphalt mixture would loseits strength and quality. It would be more worried about the sturdiness of the asphalt mixture since the crumb rubber in asphalt content changed its properties and can be utilized in additional exploration.

Keywords: waste crumb rubber,bitumen,asphalt mixture, Marshall stability value, volumetric properties

Introduction

A polymer is a large molecule with high molecular weight composed of repeat units of low molecular weight known as the monomer. The polymer can be made by two processes, namely addition and condensation polymerization. Natural and synthetic polymers with different properties such as toughness, visco elasticity and their ability to form glassy and semi-crystalline structures. Polymers are assorted in various classifications, based on how they join together or how their molecules are arranged (Yu *et al*., 2020; Fakhri and Amoosoltani, 2017).

Thermo-plastics are the most widely used polymers as they can be reshaped and can be reused again. They remolded at elevated temperatures and they retain that shape upon cooling. In thermo-plastics, the chains have concurred with the intermolecular forces, which allow the thermo-plastics to be remolded. Some examples of common thermo-plastics are polyethylene, polystyrene, polyamide and polyvinyl chloride. Thermo sets mostly have highly crosslinked, this enables them to have higher physical and mechanical properties, but on the other hand, they show reduced elasticity and elongation. One major disadvantage of thermosets is that they can neither be recycled nor reshaped on heating. It retains the shape once it is cured. It degrades upon heating instead of softening for reuse. Examples of thermo sets are epoxy resins and phenolic resins (Lei *et al*., 2018; Venudharan and Biligiri, 2017).

Elastomers are rubbery materials, and they are lightly crosslinked. This enables them to have higher elongation, increased flexibility and elasticity. Elastomers can recover their original shape even after being elongated to great extents. Typical examples are natural rubber (polyisoprene), butadiene rubber and polychloroprene rubbers. Rubber materials are advanced and complicated systems comprising several constituents, including two or more elastomers, in conjunction with multiple additives raking parts in various sectors. Vulcanized elastomers are often put through complex mechanical effort. Due to this cause, various reinforcing fillers are

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added to modify the stiffness for better and improved resistance to scratch, rupture, cutting and ripping. This is dissimilar from nearly all thermo-plastic compounds frequently used with some additives (Fakhri *et al*., 2017; Han *et al*., 2017).

Polymer adsorption on solid surfaces is commonly irreversible. Even once solely Van der Waals Interactions are necessary because of fast adsorption and desorption actions that uphold keeping particles and polymer chains in interaction with each other. In a rubber full of CB (carbon black), the impression of topological limitations spread over strong connections impulsively advance when a rigid material with a suitable surface geometry is in interaction with a soft polymer whose elastic chain sections may imitate that surface (Wang *et al*., 2020; Han *et al*., 2017).

Bitumen is a sticky and highly viscous mixture of heavy hydrocarbons obtained from the bottom in crude oil fractionation. They consist of both saturated and unsaturated, aliphatic and aromatic components with approximately 150 carbon atoms. One of the various procedures attempted to toughen bitumen with polymers is blend. It can be either scrap product material or a virgin to make polymer modified bitumen. Bitumen is a by-product of the fractional distillation of crude oil. However, it is found in natural deposits as well. It has a particular composition to provide excellent water proofing and adhesive properties (sticking property). This is a very low cost thermo-plastic polymer massively used for construction purposes such as roofing, pavement and road applications. However, it has strict temperature conditions as it becomes brittle in colder environments and softens slowly in warm environments. It generally contains about 80% by weight carbon, about 10% by weight hydrogen, around 6% sulfur and a small amount of oxygen and nitrogen, along with a few traces of metals. Properties of bitumen can be enhanced by adding various materials or by applying other methods (Guo *et al*., 2019).

The primary application of bitumen is in making roads by adding various aggregates to bitumen. This mixture is called asphalt. However, this is a bit ambiguous because in some countries, bitumen is also called asphalt. The viscosity nature of bitumen is complicated and primarily concerned by changes in its colloidal nature that rises when provided the heat. On the other hand, when the hotness is relatively high enough for the bitumen to be liquid, it behaves as a Newtonian fluid. The characteristics of bituminous materials includes oftening point, penetration and flash point.

Bitumen is an essential and widely used thermoplastic with a low cost. It now has various applications as a construction and engineering material. However, it shows unsatisfactory mechanical properties because of its strict temperature conditions as it becomes hard and brittle in colder environments and softer and fluid like in hot environments. Making bitumen challenging is by mixing it with synthetic or natural polymers that can be either unused or a polymer waste product. A good amount of polymers have been researched for bitumen modification, including compounds like polyethylene and polyolefin and various copolymers (Yang *et al*., 2020; Bressi *et al*., 2019). Recently, there has been strong attention tousing recycled plastic comprising tire rubber crumb to alter bitumen material's strength. Other advantages include greater tensile strength, superb fatigue resistance, better impact properties and lower brittle temperature.

Polymer modified bitumen (PMB) is an engineered bitumen gradeand is mainly used explicitly in making pavement. These roads bear heavy traffic and an alternative home roofing solution to resist and remain unaffected by intense weather conditions. PMB is a regular bitumen with polymer incorporation, which provides its extra strength, stripping, high cohesiveness, opposition to fatigue and deformations too making it an advantageous substance for infrastructure (Fakhri *et al*., 2017; Saberi *et al*., 2017).

Pavements designed for massive traffic and extreme climate circumstances need generally engineered designed bitumen grades. By redesigning the characteristics of standard bitumen with the incorporation of a polymer, either they are of elastomeric or elastomeric nature, advance to acquire bitumen that allows the blend to be more cohesive with improved quality of strength and noticeable higher resistance to specifications like permanent deformations and fatigue for the road pavements. Figure 1 shows low temperature cracking of asphalt pavements (Kabir *et al*., 2020; Duan *et al*., 2019).

Polymeric materials do not chemically mix or modify the chemical nature of the bitumen being enhanced. What polymer will achieve is redesign the physical nature of bitumen. Some bitumen may need modifiers to meet both high and low temperature requirements, such as a polymer. Polymers that are mainly used for

Fig. 1. Low temperature cracking of asphalt pavements (stiffness of asphalt mixture at low temperature).

this thermo-plastic modification are long chained hydrocarbon molecules that redesign the bitumen properties. Contingent on the wide monomer variety of desired properties can be achieved.

Polymer modified bitumen can provide improved performance over conventional bituminous binders but are economic concerns relatively higher price. Polymer modified bitumen can improve consistency, improve stiffness, cohesion, reduce temperature susceptibility, improve flexibility, toughness, resilience, improve resistance to in service aging and binder aggregate adhesion (Kabir *et al*., 2020; Li *et al*., 2018).

The history of asphalt emulsions and their road construction application started in the earliest of the 20th century. Nowadays, polymer modified asphalt, either natural or synthetic, which used by researchers and manufacturers to improve asphalt performance was patented as early as 1843 (Franesqui *et al*., 2019; Leng *et al*., 2018). The proper utilization of polymer modified bitumen was first recorded by the Texas Department of Highway and Public Transportation in June 1982, where it was first to get into operation in the alternative of a seal coat on a section of State Highway 327 near Silbee, they used styrene butadiene copolymer for seat coat (Zhu *et al*., 2020; Guo *et al*., 2019).

Methods to add polymer. There is no chemical change in the combination of polymer additives or the difference in the chemical nature of the bitumen being modified, a part of being present within the bitumen. The polymers will achieve re-design the physical nature of the bitumen. They can enhanced physical properties, ductility or elastic recovery can also be enhanced (Arabani *et al*., 2017).

Additive polymer usually affects bitumen's characteristics by incorporating into a determined part of the bitumen. An inter connecting matrix of polymer is created by spreading out longer chain polymer molecules through the bitumen. It is the matrix of the longer chain molecules of the included polymer which enhances the bitumen's physical specifications. Because of the polymer thermoplastic characteristics, few polymers might split up into their integral molecular blocks at a higher degree of temperatures during the process of mixing and lying and after that rein corporate into their polymer chains at lower temperatures, ambient temperatures. What has to be ascertained in practice is the degree of modification in whether the degree of improvement achieved in the bituminous mix's overall qualities is worth having and is cost effective (Arabani *et al*., 2017, Girskas and Nagrockiene, 2017).

Polymer modified asphalt is a unique product made from fine dispersion of asphalt which enhanced with polymer emulsion. Different types of methods can be used to fabricate polymer modified bitumen emulsion. The blending method to add polymer has an essential influence on the polymer network dispersal and ultimately affects its performance and strength. The technique includes the wet process which is includesthe mixing of polymer, bitumen and aggregate at an elevated temperature that is at process temperature. The dry process includes mixing bitumen and aggregate at process temperature. In meanwhile, polymer sprinkled over them at room temperature and integrated over the process temperature. The solution phase in this bitumen is first mixed with some organic solvent like xylene, kerosene at room temperature, as asphalt is also an organic solvent. Both will be soluble in each other forming solution of polymer from the same solvent but at elevated temperatures (Girskas and Nagrockiene, 2017).

Polymer modification is now of greater interest and widely used during the last 40 years. Various investigated polymers polyethylene (PE), ethylene-butyl acrylate (EBA), styrene-isoprene-styrene (SIS), polyester, ethylene-vinyl acetate (EVA), acrylic fiber and thermoplastic elastomers styrene-butadiene-styrene (SBS), styrene-ethylene/butylene-styrene (SEBS) are previously used. Figure 2 shows the popular polymers for modification from the colloidal structure of bitumen (Yang *et al*., 2020; Chen *et al*., 2019).

The literature survey found that a lot of work has been done in this field from various polymers. Some of their impacts after their implementation are discussed. Elasticity is the main factor of rubber that increases flexibility in the road. The use of rubberized asphalt as a pavement material because of its high durability, also reduces road noise. Its heat sensitivity limits and cold

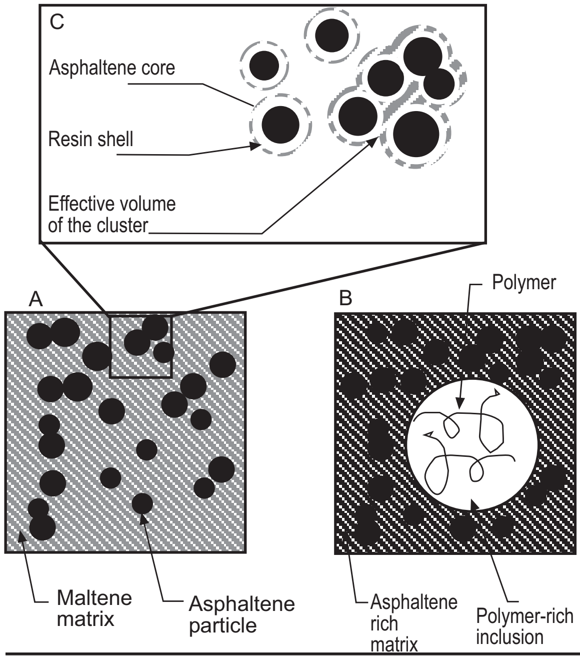

Fig. 2. Popular polymers for modification.

bituminous mixture. Improves resistance to cracking and rutting in new pavements. Table 1 shows the advantages and disadvantages of plastomers and thermoplastic elastomers (Yang *et al*., 2020; Duan *et al*., 2019).

Ethylene-vinyl acetate (EVA) modified asphalt binders show dispersed polymer components in a continuous bitumen matrix. Morphology (binding) increases and storage stability reduces by the rise in the EVA concentration. The styrene butadiene rubber (SBR) results show low temperature ductility, increased viscosity, improved elastic recovery and improved cohesive, adhesive pavements. They disperse speedily and uniformly in every part of the material and form a reinforcing network structure.

Elvaloy or ethylene glycidyl acrylate (EGA), when mixed with bitumen Elvaloy acted like an elastomer, probably because of ethylene's main effect in the molecular chain. Separation in storage and transportation is the major problem that occurs after the reaction. The sensitivity of the blends to moisture harm was found to decrease by the addition of Elvaloy. The lowest viscosity at all tested temperatures could significantly benefit during applications (Yu *et al*., 2020, Zhu *et al*., 2019).

Addition of crumb rubber in bitumen. The increase in the number of vehicles in Pakistan day by day is causing major environmental issues as it is increasing the number of waste tires. The crumb rubber material examined as an enhancer in hot asphalt blend is a reasonable constructing method and a better choice for pavement. There have been many studies on crumb rubber modified asphalt mixtures. The inclusion of crumb rubber enhanced the physical properties of the rubberized bitumen binder, as indicated by various testing. The main advantage of crumb rubber is increasing HMA stiffness at high working temperatures (Yu *et al*., 2020; Han *et al*., 2017).

Materials and Methods

Preference of material. The materials used to modify bitumen with polymer include the crumb rubber (which majorly has NR and EPDM). Bitumen (60/70 grade,

Table 1. Advantages and disadvantages of plastomers and thermo-plastic elastomers

Categories	Examples	Advantages	Disadvantages
Plastomers	Polyethylene (PE), Polypropylene (PP)	Good high temperature properties and relatively low cost	Limited improvement in elasticity and phase separation problems
	Ethylene-vinyl acetate (EVA), Ethylene-butyl acrylate (EBA)	Relatively good storage stability and high resistance to rutting	Limited importance in elastic recovery and limited enhancement in low temperature properties
Thermoplastic elastomers	Styrene-butadiene-styrene (SBS), Styrene-isoprene-styrene (SIS)	Increased stiffness, reduced temperature sensitivity and improved elastic response	Compatibility problems in some bitumen, low resistance to heat, oxidation and ultraviolet and relatively high cost
	Styrene-ethylene/butadiene-styrene (SEBS)	High resistance to heat, oxidation and ultraviolet	Storage instability problems, relatively reduced elasticity and high cost

according to NHA Pakistan). PAK HY oils obtain bitumen of several grades for their testing from NRL (National Refinery Limited). According to National Highway Authority for the climate of Karachi, the suitable bitumen grade is 60/70. So, they approached PAK HY oils and they provided the MSDS, which claimed that the bitumen grade is 60/70. For the bitumen grade verification, The penetration test using a penetrometer according to ASTM D-5, showing the results in Table 2.

The second raw material for the sample preparation is crumb rubber which was purchased from the local market. Thus, it did not have any useful information about the blend composition and components included in the polymer blend (crumb rubber). So, to identify the components and FTIR (Fourier-transform infrared spectroscopy) was conducted. FTIR analysis of bitumen was examined using a Thermo Scientific Nicolet iS-50 FTIR spectrometer. A small amount of bitumen sample was selected. The scans were 20 with wavelengths ranging from 4000 cm^{-1} – 500 cm^{-1} and the spectra were obtained from a 200 micrometer diameter sampling area. An analytical method used to classify organic materials also measures the absorption of infrared radiation by the sample compared tothe wavelength. The infrared absorption bands show structures and molecular components. The spectrum was observed after the test is given in Table 3 and Fig. 3 (Zhu *et al*., 2020; Guo *et al*., 2019; Yu *et al*., 2019; Han *et al*., 2017).

Table 3 and Fig. 3, it can be seen that in the spectrum, the main group is represented with a wavelength of around 1100 cm^{-1} are ketones which are part of EPDM and NR (C-C stretch) with a lot of other groups present which again are a part of EPDM and NR. The wavelength around 700 cm^{-1}shows that these are alkanes, with a wavelength of around 740 cm^{-1} and 870 cm^{-1} showing aromatics. These all are part of EPDM. The wavelength of around 1393 cm^{-1} represents alkenes and around 2800-2950 cm^{-1} represents alkanes. These groups are a part of NR. Few other groups shown by wavelength

Table 2. Penetration test results

Bitumen	Penetration value ($1x\ 10^{-1}$ mm)	Penetration time (s)
Depth 1	65.5	5
Depth 2	60.4	5
Depth 3	70.0	5
Mean value	65.3	

Table 3. Observed spectrum of infrared absorption bands

Molecular motion	Wavenumber cm^{-1}	Part
CH_2 Bend (4 or more) ~ Alkanes	~720	EPDM
C-H Bend (ortho) ~ Aromatic	770 – 735	EPDM
C-H Bend (meta) ~ Aromatics	~ 880	EPDM
S=O Stretch ~ Sulfoxides	~ 1050	Crosslink agent
C-C stretch ~ Ketones	1300 – 1100	EPDM and NR
C-O stretch ~ Alcohols	1260 – 1000	Stearic acid
C-H in plane bend ~ Alkenes	1430 – 1290	NR
C=O stretch ~ Aldehydes	~1725	Stearic acid
C-H stretch ~ Alkanes	2950 - 2800	NR

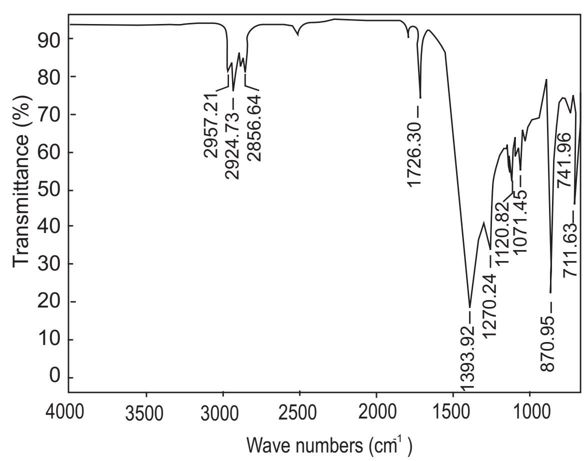

Fig. 3. Observed spectrum of sample material against wavelength.

1071.45 cm^{-1}, 1270.24 cm^{-1} and 1726.30 cm^{-1} represent the crosslink agent and additives present in the rubber mixture. So, in comparison to these common Table 3 values, the obtained results were checked and it was found that it is a blend of EPDM and natural rubber. Figure 4 shows the structures of EPDM (ethylene propylene diene monomer) and natural rubber (Khan *et al*., 2016).

Process selection. A dry process was applied throughout this study for the natural and crumb rubber modified asphalt mixtures. In this research, several stages of laboratory examination were conducted. When the experiment with wet process found that there were many chances that solid particles stuck in the pan, non-

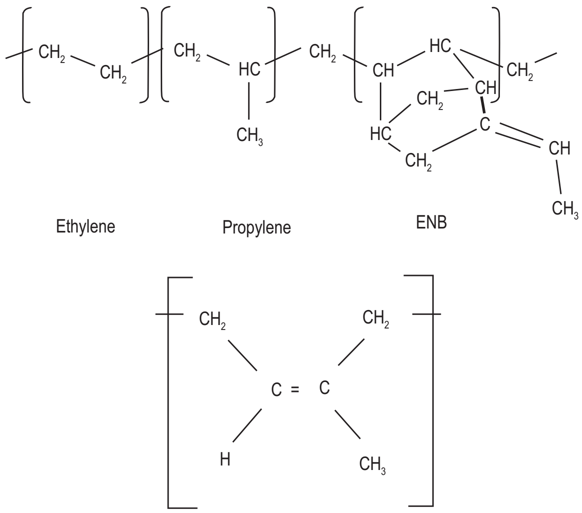

Fig. 4. Structures of EPDM (ethylene propylene diene monomer) and natural rubber.

homogenous dispersion in the sample and difficulties in figuring out whether the polymer melts or not were observed, after going through the results of experiments concluded that,stability on average is relatively better in dry process. Flow is more in the dry process but not as that to compare strength. Density also differs with a small amount which can be overcome by increasing stability in the dry process. Hence, they decided that the dry process must be used for further experiments

Sample preparation. For sample preparation, four models started from 1% to 7%, with 2% each. The models were made based on increasing weight percentage. Crumb rubber is incorporated in bitumen. The total weight for each composition is 300 g. Crumb rubber is added gradually in the bitumen samples. The whole preparation of the sample was completed in six steps. The bitumen sample was taken in a pan. It was heated for approximately 15-20 min until it melted. After the bitumen's viscosity was reduced, Crumb rubber was sprinkled over the bitumen (through the dry process) periodically. Throughout, the sprinkling, manual stirring was done. This process was continued for 30 min until all crumb rubber was sprinkled into the pan. After complete mixing, the polymer modified sample of bitumen was poured into the container for later testing. These steps were followed according to the given composition represented in Table 4.

Characterization of polymer modified bitumen. This study performed softening test, penetration test, and Marshall Stability Test. All the testing standard methods were followed accordingly. Softening test and penetration test were done on a polymer modified bitumen sample and a Marshal test was done by adding various aggregates.

Softening tests. Softening point recognizes the temperature at which the bitumen achieves a specific softening degree within the test conditions of IS: 1205–1978, applicable standard ASTM D 36. The test is performed by using a ring and ball apparatus. A ring made of brass beside the bitumen sample is dispersed in fluid (water or glycerin) at a given condition and temperature. A steel ball of a fixed mass is situated on the bitumen selection and the liquid medium is heated at a degree of 5 °C/min. Temperature is observed after the unstiffened bitumen material finally meets the metal dish at a certain distance. Commonly, a higher softening point specifies lower temperature liability and is selected in hot climates. Figure 5 shows the softening point test setup (Wang *et al*., 2020; Khan *et al*., 2016).

Table 4. Different compositions of the sample of polymer modified bitumen

Factors	Weight % of crumb rubber			
	CR/ MB/01	CR/ MB/03	CR/ MB/05	CR/ MB/07
Time (min)	30	30	30	30
Temperature (°C)	180-190	180-190	180-190	180-190
Mass of crumb rubber (g)	3	9	15	21
Mass of bitumen (g)	297	291	285	279
Total mass of sample (g)	300	300	300	300

Penetration test. It processesIS 1203–1978, applicable standards ASTM D5 the softness or hardness of bitumen by defining the penetration in tenth mm to which a typically loaded needle will enter straight up in 5 sec. The penetrometer comprises a needle assembl age with an entire heaviness of almost 100 g and a device for discharging and fastening at any point. The bitumen is moderated with uniformity, stirred methodically and removed into containers at a depth of 15 mm beside the predictable penetration. It must be completed at a precise temperature of 25 °C. Any inexactness massively influences penetration value with favours to driving temperature, the needle's magnitude, weight located on the needle and the test temperature, as shown in Fig. 6 (Wang *et al*., 2020; Arabani *et al*., 2017).

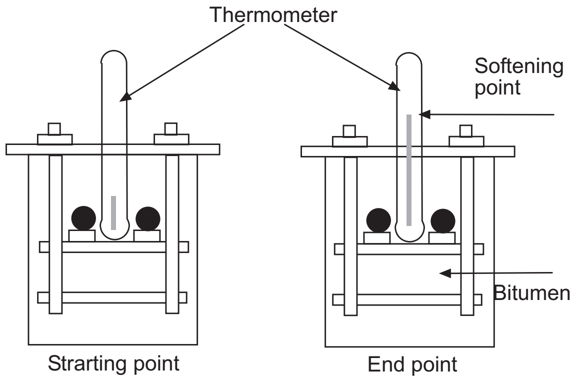

Fig. 5. Softening point setup.

Marshall stability test. This test is performed IS 208–1978, applicable standards ASTM D113 to get the optimized binder content for the aggregate mix type and traffic strength, as present in Fig. 6. This is the test that directs us to draw marshall stability with % composition bitumen. The apparatus for the marshall stability test consists of the steps containing sample mold assembly, including mold cylinders of width 10.16 cm and height 6.35 cm, extension collars and base plate. Sample extractor for pulling out the compacted sample from the mold. A specific bar is essential to transfer the weight from the extension collar to the upper, showing ring attachment whereas, removing the specimen. Compaction hammer 4.5 Kg sliding weight with a flat circular tamping face made to offer a free fall of 45 cm, comprising 20x20x45 cm wooden block capped with 30x30x2.5 cm MS plate to hold the mold assembl age in placein the course of compaction. Mold holder comprising of spring tension device intended to hold compaction mold in position on compaction pedestal (Duan *et al*., 2019; Lei *et al*., 2018).

Fig. 6. Penetration test.

The breaking head contains lower and upper tube-shaped sections having an inside range curvature of 5 cm. The more extended area is mounted on a base with two up right guide rods, facilitating insertion in the holes of the upper test segment. The resulting general equipment required for testing is a loading machine, water bath, hot plate or oven and various equipment like containers, handling and mixing tools.

Preparation of samples for marshall testing. Aggregate (1200 g) mixed and heated in the oven, bitumen is added to the mixing temperature. These materials are mixed in a heated pan with preheated mixing toolsat the Department of Civil Engineering Project Lab, NED University of Engineering and Technology, as shown in Fig. 7. The mixture is reverted to the oven and re-heated to the compacting temperature. The mixture is sited in a heated marshall mold with a base and collar; then, the mixture is spaded around the mold's sides. The filter paper is positioned under the sample on top of the model. The mold is placed in the Marshall compaction pedestal. The sample is compacted with 75 blows of the hammer and overturned and compacted in the other face with a similar number of blows. After that, the mold is overturned. The base is detached with the collar on end and the sample is extracted by pushing it out of the extractor. The model is allowable to cool for some hours.

Specimens are heated in a given water bath for thirty to forty minutes or possibly in an oven for 2 h.The models are then detached from the shared water bath and put in the lower section of the breaking head. The upper section of the sample's breaking head is sited in the desired position and the entire assembl age is placed in part on the testing machine. The flow meter is positioned over the posts and is regulated to read zero reading. The 50 mm/min load is applied till the maximum load reading is attained. Simultaneously, the flow on the flow meter was also noted. Figure 8 represents the prepared sample of different compositions.

Results and Discussion

This research was conducted to see the effects of bitumen's different mechanical properties with different weight compositions of crumb rubber (EPDM and NR). The overall results showed that when increasing the

Fig. 7. Different samples of bitumen for Marshall stability.

amount of crumb rubber in bitumen the mixture showed enhanced mechanical properties. The test was conducted upto the weight percent composition of 7% crumb rubber in bitumen and as expected, better results were observed at the highest amount of crumb rubber. EPDM and NR not only gave flexibility to the very brittle bitumen but also increased its impact strength and hardness, making it to be used in hot climates with heavy traffic giving better road performance. The raw materials were first analyzed using the FTIR characterization technique for the crumb rubber and penetration test for bitumen. The first penetration test was done on the bitumen to confirm its grade. The penetration technique used for bitumen is a simple method, where its consistency is checked. According to the results, it was found that the mean value was 65.3 mm. The readings also showed that the bitumen grade was 60/70, which is good for road construction, where climatic conditions are hot and humid.

Fig. 8. Prepared sample with different compositions of bitumen.

Softening tests (ASTM D-36). The results were obtained using the standard ball and ring apparatus (ASTM D-36). Figure 9 shows the weight percentages of crumb rubber along with the mean temperatures obtained from softening tests. It can be observed that there is an increase in temperature by 2 °C when comparing the bitumen mixture containing 1% crumb rubber composition with the 7% crumb rubber composition. As crumb rubber increases in the bitumen, the mixture becomes stable, showing better binding property at higher temperatures. The crumb rubber, when added as a binder in the bitumen is giving more strength and flexibility to the very viscous unmodified bitumen. It has been observed and shown by the softening test results that bitumen becomes more susceptible to higher

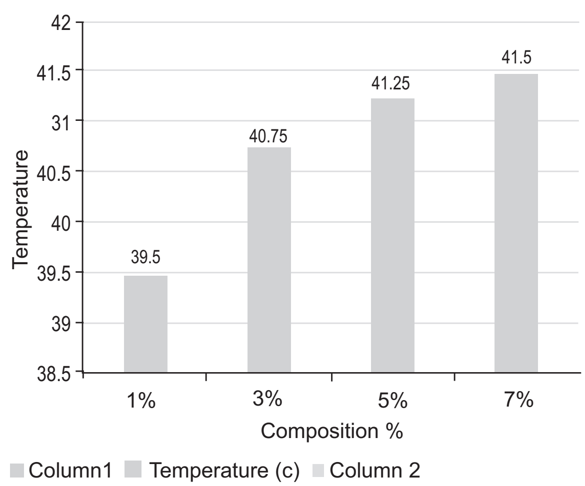

Fig. 9. Effect of temperature on different crumbed rubber compositions in hot bitumen..

temperatures. Also, this mixture will give high rutting resistance because the crumb rubber (EPDM and NR) is uniformly mixed in the bitumen for a longer time and at a controlled temperature which causes more homogeneity and stability in the mixture. The mixture is capable of with standing higher temperatures without being deformed, this is happening because of EPDM since, it can with stand high temperatures and also give flexibility to the mixture and because of NR, the mixture gets strength and also flexibility. Overall, the results show that this bitumen and crumb rubber mixture can be easily worked at high temperatures and better performance when used in hot climate regions.

These studies also showed very similar results for softening tests, where it was observed that the presence of crumb rubber in bitumen mixture if mixed uniformly, is capable of with standing high temperatures and also giving flexibility to the mixture (Kabir *et al*., 2020; Yang *et al*., 2020; Chen *et al*., 2019; Guo *et al*., 2019).

Penetration test (ASTM D-5). The results were obtained using the standard penetrometer (ASTM D-5). Figure 10 shows the weight percentages of crumb rubber and their mean depths obtained from penetration tests. It shows that test results from penetration show that by increasing the weight percentages of crumb rubber (EPDM and NR) in bitumen, the depth gradually decreases, proving that the mixture is becoming more stable by giving good impact strength. Here, the crumb rubber in bitumen acts as a binder. When added to the bitumen, crumb rubber adsorbs the lighter bitumen components and then disperses completely in the mixture. By increasing the amount of crumb rubber in the bitumen, the interaction between the bitumen and crumb rubber increases, giving good mechanical properties to the mixture. Comparing the 1 % crumb rubber composition in bitumen to the 7% crumb rubber composition, a decrease of 7.54 mm of depth is observed, which ultimately proves that the mixture with a higher percentage of crumb rubber gives better resistance to asphalt binder deformation. EPDM and NR both have elastomeric properties. NR being the most flexible elastomer is a major contributor to flexibility and strength to the bitumen mixture. However, both EPDM and NR are increasing strength in the bitumen mixture. So, the result shows the increase in resistance to penetration when increasing the amount of crumb rubber in the bitumen mixture.

According to previous studies, the presence of crumb rubber in bitumen increases the flexibility and strength

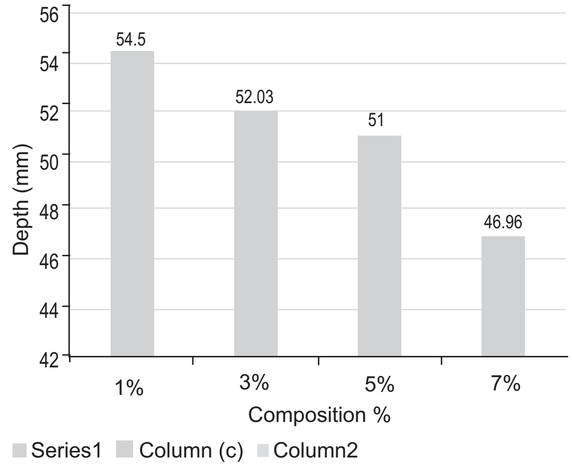

Fig. 10. Penetration values for samples of different crumbed rubber compositions in hot bitumen.

of the whole mixture since rubbers generally have elastomeric properties. With the increase in the amount of crumb rubber in the bitumen mixture it was getting difficult for the needle to penetrate more in the mixture, and hence the results were observed, giving less penetration and more strength. (Yu *et al*., 2020; Wang *et al*., 2020, Yang *et al*., 2020; Duan *et al*., 2019).

Marshall stability test (ASTM D-113). Figure 11 shows samples with different crumbed rubber compositions in hot bitumen at various loads. Marshall stability tests were performed to check the load sustained by the bitumen mixture at constant loading. According to the results obtained by increasing the amount of crumb rubber (EPDM and NR) in bitumen, the Marshall stability also increases in strength of the mixture. By adding the crumb rubber as a binder in bitumen, the mixture gets good adhesion properties. From Fig. 11, it can be observed that the Marshall stability parameter kept increasing by the amount of crumb rubber percent, which means that the mixture became stable. Its load bearing capacity is also being increased. In simple words, the mixture's hardness increased because of crumb rubber (EPDM and NR). This enhanced effect of the mixture is because of the crumb rubber's elastic property (EPDM and NR). So, the bitumen mixture with crumb rubber can sustain a greater load than the bitumen mixture without adding crumb rubber. It can be observed that if crumb rubber is added to the bitumen, it will give good elastic behaviour making. The bitumen mixture was feasible to be used for road pavements which will easily bear the greater load with fewer

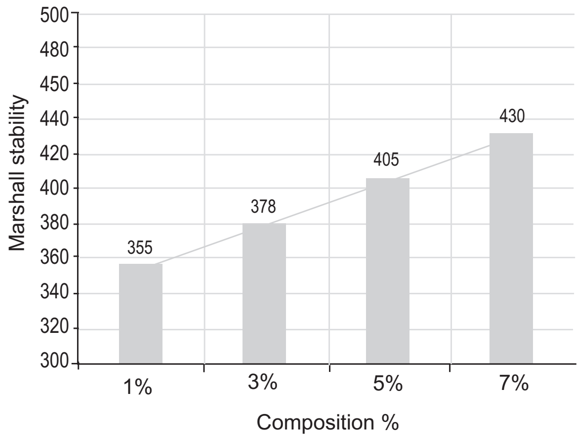

Fig. 11. Samples with different crumbed rubber compositions in hot bitumen at various loads.

deformations and also give better resistance and greater strength to the roads.

The results compared to the previous studies, where it has been observed that the incorporation of crumb rubber in bitumen has an increasing effect on strength. According to the study, this improving effect is because of the elastic behaviour of crumb rubber. The same trend was observed in this study (Fakhri and Amoosoltani, 2017; Han *et al*., 2017; Venudharan and Biligiri, 2017; Khan *et al*., 2016).

Conclusion

Softening test results of crumb rubber (EPDM and NR) modified bitumen show that increasing the weight percentage of polymer in bitumen if properties to soften at a given temperature. This means that a bitumen modified with crumb rubber will show high temperature susceptibility and improve performance in hot climatic conditions. Penetration results of crumb rubber (EPDM and NR) modified bitumen exhibit greater penetration resistance when the weight composition of both the polymers is increased in the bitumen. This means that the penetration resistance of polymer modified bitumen rises with the increasing weight percentages of the polymer. So, a road pavement of bitumen modified with these polymers will enhance its hardness. Marshall's results of crumb rubber (EPDM and NR) modified bitumen exhibit that as the composition of crumb rubber increases, the bearing capacity of specimen increases, which means the Marshall stability of material gains. This means that the resistance load of polymer modified bitumen increases with the increasing weight percentages of the polymer. So, a road pavement of bitumen modified with these polymers will enhance its load bearing capacity. Crumb rubber provided us with optimum results but its combination with some other polymer might better result. The wet process can be applied too for the same composition to make a comparative study. Nevertheless, more exploratory and field studies are prescribed to examine the impact of reclaimed asphalt pavement and crumb rubber powder on the presentation of warm blend asphalt mixtures within sight of the organic additive.

Acknowledgment

The authors would like to acknowledge the Department of Polymer and Petrochemical Engineering and Department of Chemical Engineering, NED University of Engineering & Technology, Karachi, Pakistan, for supporting this research work

Conflict of Interest. The authors declare no conflict of interest.

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