Effect of Natural Rubber, Carbon Black, and Copper Slag as Construction Materials in Flexible Pavement: A Review

S. Asvitha Valli and Sreevalsa Kolathayar

Abstract In this paper, the effect of natural rubber, carbon black, and copper slag in the construction of flexible pavement is discussed. Natural rubber is used as a construction material because of its abundant availability and for its high tensile strength and good vibration absorption properties. Copper slag is obtained as a by-product of copper production, which is available in ample in India. In the year 2017, the volume of copper produced in India is nearly 134,790 metric tons. So many researchers studied the effect of copper slag on pavement construction and observed convincing results in improving the mechanical properties of the mix. Carbon black is used as a bitumen modifier in the flexible pavement which improves the properties like tear strength, resilience, and conductivity. It is observed that with 10% carbon black the creep value is lowered. The copper slag, when used as fine aggregate in various mixes, proved the improvement of volumetric and mechanical property of the mixes. It is also found that the utilization of natural rubber, carbon black as bitumen modifier, and copper slag as a substitute for fine aggregate improves the properties of the pavement significantly.

Keywords Waste management · Natural rubber · Copper slag · Carbon black · Pavement

1 Introduction

A pavement consists of superimposed layers of materials to transfer the vehicle load to the soil subgrade. The various layers in a flexible pavement are soil subgrade, subbase course, base course, and surface course. The subgrade serves as a foundation for the pavement. The subbase course functions as a structural support and also helps in

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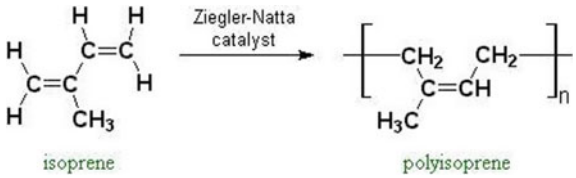

Fig. 1 Ziegler–Natta polymerization

improving the drainage. The base course contributes to load distribution and surface drainage. This base course is generally made up of granular materials like crushed stone and crushed slag. The surface course should be made up of superior quality materials because of its direct contact with the traffic. The base course and subbase course are generally constructed using aggregates which are in greater demand in the market.

In recent years, studies have been done using the waste materials in the construction of pavements. This will lead to the usage of cost-effective construction material and also the effective disposal of the waste [1]. It is also evident from the previous researches that incorporation of copper slag, rubber, and carbon black improves the performance of the bituminous mix [2]. This bitumen modified with polymers or waste materials mainly focusses on the mechanical and physical properties of the rubberized mixture. It is found that rubberized bitumen are sensitive when exposed to heavy vehicle load and variation in temperature [4]. The use of copper slag as a partial replacement of fine aggregate in the mix proved a good interlocking property.

2 Natural Rubber

Natural rubber is an archetype of all elastomers. Rubber is obtained from the bark of Hevea tree in the form of latex. The rubber is extracted from the latex after treating it through several steps which include preservation, concentration, coagulation, dewatering, drying, cleaning, and blending. Depending on various factors like viscosity, oxidation resistance, and rate of cure, it is classified into various grades for marketing. Modified natural rubbers are available as epoxidized natural rubber, deproteinized natural rubber, and thermoplastic natural rubber.

Natural rubber is a quintessential polymer for engineering applications. Natural rubber chemically known as polyisoprene is diene polymer. These diene polymers have a carbon–carbon double bond in its backbone. This polyisoprene is obtained by Ziegler–Natta polymerization (Fig. 1).

2.1 Properties of Natural Rubber

- High tensile and tear strength.

- Resistance to fatigue.
- Insoluble in water, acetone, dilute acids, and alkalis.
- Absorb vibration.
- Elastic in nature.

The addition of carbon black, anti-degradants, softeners, and the proper vulcanization system will help in achieving the required properties. This polymer-modified bitumen is found to increase the quality of bitumen. This reduces the permanent deformations due to overload and is also unaffected by the changes in the atmospheric temperature.

2.2 Natural Rubber–Bitumen Mixes

Bitumen is manufactured from the distillation of crude oil during petroleum refining. The crucial characteristics of bitumen are adhesiveness, waterproof, thermoplastic, durable, modifiable, and recyclable as a construction material. It is found that 85% of the bitumen obtained is used as the binder in the construction of pavements [5]. In the early ages, rubber was mixed with bitumen to enhance the performance of the pavement. The rubber-modified bitumen was beneficial in extreme weather conditions, and the expansion and contraction due to the varying temperature were arrested by the elastic behavior of rubber [6]. Previous studies determined that the incorporation of rubber in bitumen proves the long-run performance of the pavement.

Due to the recent developments and lack of maintenance of pavements, the service life of pavements was decreased [7]. At a higher temperature in tropical areas, the bitumen runs similar to viscid liquid which proves the lack of viscoelastic and rheological properties in bitumen. This results in the deformation of the pavement surface [9]. On the other hand, at cold climate, the bitumen becomes inflexible and stiff resulting in the fatigue failure. So these leads to the inclusion of other materials like copper slag, carbon black in the pavement construction (Fig. 2) [10].

Deshmukh and Kshirsagar [3] performed an experimental study by varying the percentage of rubber by 0, 8, 10, 12, and 14% and observed that penetration value decreases as the percentage of rubber increases. This proves that the inclusion of rubber makes the bitumen mix harder. An increase in the softening point value with the increase in the rubber content is observed, which proved that rubber-modified is less vulnerable to temperature variation. Ductility value is found to be decreased with the increase in rubber content which proves that the addition of rubber makes the bitumen mix stiffer.

3 Carbon Black

Carbon black is a product of incomplete combustion. It is a commercial form of solid carbon. Carbon black typically contains 95% of pure carbon with minimal quanti-

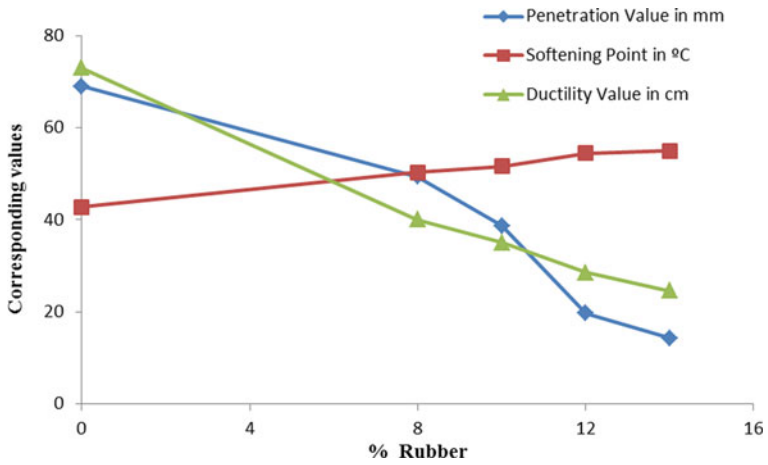

Fig. 2 Variation of experimental values with different percentages of rubber

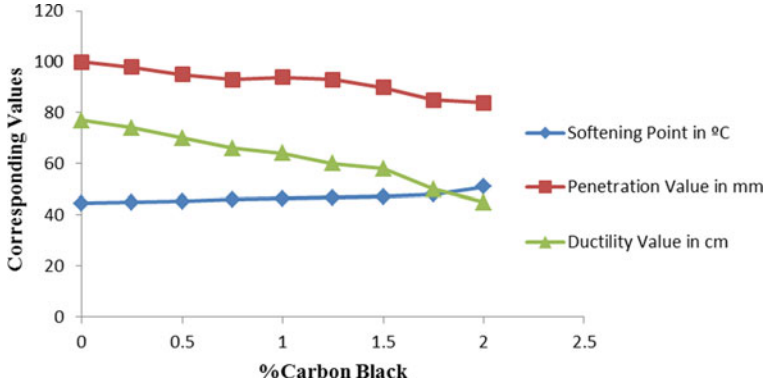

Fig. 3 Variation of experimental values with different percentages of carbon black

ties of hydrogen, nitrogen, and oxygen. It is used with other materials to improve their physical, electrical, and optical properties. Carbon black helps in increasing the properties like tear strength, resilience, and conductivity. It is used as a rubber reinforcing agent in the manufacturing of tires. This carbon black acts as a chemical strengthener in rubber. The carbon black is of two types like pyrolysis carbon black and petroleum carbon black. The pyrolysis carbon is economical compared to the petroleum carbon black. The pyrolysis carbon black is the second product of the tire pyrolysis industrial plant.

Experimental studies have been done by Saritha and Kiran Kumar [8] with different percentages of 0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, and 2% Carbon Black (CB) and observed a slight variation in the softening point, penetration, ductility values as shown in Fig. 3.

3.1 Copper Slag as Aggregate

The copper slag is added to the fine aggregate which improves the interlocking properties, volumetric, and mechanical properties of the bituminous mix. The density of the mix is increased by 16%, which shows the improvement in the interlocking property. The addition of 25% of CS shows favorable results in the Marshall quotient to the values closer than the conventional mix. The fatigue life of the bituminous mix is improved by the use of copper slag as a fine aggregate. This also increases the abrasion resistance of the pavement.

4 Conclusion

Thus the remains of natural rubber can be effectively used as the construction material for pavement. The penetration value obtained from experimental studies for natural rubber is in between 20 and 50 mm. This can be used in any climatic conditions. The softening point is between 50 and 55 °C; this can be used in warmer regions. The viscosity test proved that the resistance to flow increases with the increase in natural rubber. The incorporation of natural rubber thus improves the performance of the bitumen.

The asphalt binder does not have the electrical and thermal conductivity, but the addition of carbon black of different sources improved various properties like anti-aging, electrical, and thermal conductivity. This helps in improving the behavior of pavement at varying climatic conditions. The copper slag obtained from the extraction of copper can be used as a construction material because of its physical properties. This improves the interlocking property of the aggregate, thereby increasing the load transfer capacity of the pavement. Thus, the addition of natural rubber, carbon black, and copper slag in various proportions with the bituminous mix improves the behavior of flexible pavement.

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