Utilization of Plastic in the Construction of Flexible Pavements

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***Abstract*—Plastics will remain unchanged on the planet for up to 4500 years. Plastic is a material that comes in a variety of synthetic and semi-synthetic varieties and can be cast into a variety of solid pieces. It is user-friendly and long-lasting, but it is not environmentally friendly or biodegradable. The disposal of plastic waste is essential for preserving the environment. The practice of using plastic in pavements has addressed numerous issues which relate not only to the disposal of used plastics but also in reducing the amount of bitumen required in surface dressing. In addition, it helps to increase the performance of roads significantly. This paper is focused on the study of the use in road building of disposed products and reviews the effective plastic use in road development through different methods of construction and its effects on the performance of roads.**

Keywords: *Plastic, Modifier, PET, HDPE, Bitumen.*

I. Introduction

Managing plastic waste is one of the critical issues that the whole world is facing at this time. Its sustainable, complete and economical disposal method is still not found. However, using plastic waste in surface dressing of the highways, known as plastic roads, has proved to solve this problem to some extent. This technology was patented by Prof. R. Vasudevan [1]. The plastic is used in the shredded form through dry or wet process. This provides a better performing pavement in addition to the economical disposal of the waste. The plastic roads are being constructed in different countries of the world including India, United Kingdom, Netherlands, Indonesia, etc. One of the most dangerous materials, Polyvinyl Chloride results in increased stability,strength of bitumen mix along with improvement in resistance to permanent deformation of the pavement.The likely use of High Density Polyethylene in road building in Ghana was shown byAppiah Johnson et al.[2]. The results have indicated improved softening point, a lower value of penetration and an improvement in the binder's whole absolute and dynamic viscosities.The study also showed that the use of plastic modified bitumen as alternative recycling method for the management of plastic waste worldwide has a broad potential and as non-commercial, modified binder for road construction. Plastic roads using a plastic-asphalt blend are being constructed in many places in Indonesia. The carbon emissions are reduced by approximately 3 tonnes per km by using 1 tonne of plastic waste for every one kilometer length of road as compared to conventionaltechniques of construction [3].

II. Waste Plastic Collection

In road construction, waste plastics use depends on high quality storage, cleaning and processing system. Films of 60 micron thickness for carrier bags and disposable cups, hard foams of any thickness, soft foams of some thickness,plastic laminates with a thickness of up to 60 microns types of waste may be utilized in the construction of roads. Hence, waste separation is important [4].

III. Modifier Selection

Many factors influence the modifier chosen for a project, capacity of construction, availability, expense, and anticipated performance. The dry process involves the direct incorporation of waste plastic together with aggregate to produce a modified plastic bituminous concrete mixture in bitumen and the wet process requires the combination of bitumen and waste plastic to make a mixture of bituminous plastic modified concrete. For a long time, polymer based bitumen has been used to improve the efficiency of asphalt pavements.In the plain bituminous concrete mixtures, Zoorab&Suparma[5] has registered improved lifespan and fatigue life by recycling the polypropylene and Polyethylene of low density. The tolerance to the deformation of mixed asphaltic concrete with low polythene density was improved as compared to unmodified mixtures.

IV. Construction Methods

A. Dry Process

National Rural Roads Development agency [6]and Indian Roads Congress (IRC) [7]recommends use of 2-3 mm size shredded pieces of plastic to be used for better coating and spread of the aggregates. The plastic waste is applied to the aggregates and is heated at a temperature of

ISBN: 978-93-91355-11-1

170^{0}C. Further, bitumen is heated to 160^{0}C and mixed with the plastic laminated aggregates. The optimum amount of shredded pieces of waste plastic is found to be 8% and a marked improvement in the split tensile strength and Marshall Stability was observed by Mishra and Gupta [8].In dry process, the plastic waste is shredded and is applied to the hot aggregates. For improved coating and spread on the aggregates, the IRC[7] and the National Rural Roads Development Agency [6] recommends that the waste plastic should be shredded to 2-3 mm. There is not more than 1 percent of dust and other atmospheric contaminants. The shredded waste is then mixed in with the hot aggregates at 170°C. Over the aggregates the shredded waste plastic melts softly and forms a paste [9]. Before mixing with plastic coated aggregates, bitumen is heated at 160^{0}C and then used in construction. The volume of shredded plastic wastes in bituminous blends should be 5% to 10% of the overall bitumen weight, with an optimum 8%, according to laboratory tests [3,6,7,8].

Mishra and Gupta [8] observed a substantial improvement in various parameters such as Marshall Stability and indirect tensile strength for dry process outputs in combination with wet process outputs. This shows that higher loads and deformation resilience are more tolerable. For dry method of the combination of waste plastics, aggregates and bitumen to make flexible pavements, Professor R. Vasudevan was granted patent in 2006 [1,3].

MacRebur, a UK-based company, processes and converts waste plastics into pellets before heating them up to 160-180^{o}C in a mixture of asphalt or bitumen. These pellets melt and blend in with the bitumen mixture.

B. Wet Process

The powered waste is spilled onto hot bitumen. The bitumen added to the aggregates after mixing with shredded waste, the temperature is kept between 155-165^{0}C [10].

Before being mixed with aggregates, the powdered waste is mixed with bitumen. The temperature for this process is kept between 155^0 C to 165 ^{0}C, and an even combination of plastic and bitumen must be assured [10]. According toAsare et al. [10]and Sahu and Singh [9], waste plastic powder can make up 6-8 percent of the bitumen blend.

A central mixing plant (CMP)can be used for the dry phase. In the conveyor belt, the shredded plastic is mixed in with the aggregates. This is poured into the steaming cylinder. The bitumen is applied after the aggregate has been covered with rubber. After that, the mixer is put onto a dipper lorry and shipped for road laying. CMP allows for improved temperature regulation and mixing of the paint, resulting in a more even coating.

V. Tests on Plastic Modified Bitumen and Polymer Coated Aggregates

A. Impact and Crushing Value of Polymer Coated Aggregates

The overall crushing value can be used to assess an aggregate's ability to withstand crushing. According to the test results, combined losses of 25.47 percent, 18.64 percent, 17.26 percent, 16.97 percent, 16.76 percent, 16.33 percent, and 16.89 percent was found in the aggregates [11].To improve the consistency of the paving, a low aggregate crushing value is desired. The aggregates to be used in the surface layer should demonstrate an aggregate loss of less than 30%.This type of aggregate is appropriate for this study, based on the results as it is to be used on the surface course layer.The coating of aggregates with PET has shown to improve the strength and properties of the aggregates. This can help to fill surface pores by means of the PET-coated aggregates. Impact value is used to determine the aggregate's brittleness. By covering the aggregate with polymer, the decrease in void sand air cavity in the aggregate is observed. Cracking is avoided by the polymer layer formed over it. The aggregate's strength can be improved by coating it with PET. This can be proved by a comparative study between modified and plain aggregates.In comparison, Kumar and Vikranth[12]used Polypropylene (PP) modifier. The percent loss in the aggregates reduced as the volume of PP increased, according to their findings. Gurpreet Singh and Rajiv Chauhan[13] investigated the use of PET to coat aggregates. In comparison to this analysis, Kumar and Vikranth's[12]impact test indicates a lower value. This may be because a new kind of plastic was used. The melting point of PP is 164°Cand252°C for PET [14].As a result, PP's aggregate coating quality will be better than PET as it melts rapidly.New raw material for flexible paving can be found in the dry coating process of aggregates with polymer (PET and latex).The lowest overall loss for the crushing impact measure is 16.34% with the PET content 9%, and the lowest loss for the impact value analysis is 8% with the PET content 13%. The inclusion of latex has increased the aggregate's resilience, resulting in a very low percentage failure value of 3.48 percent when an effect test is conducted. When aggregate is covered with a rubber, the consistency of the aggregate may be increased. If the overall strength improves, the pavement's durability can be increased.

B. Hardness and Stripping Tests

The control sample had a hardness of 38.42 HD. PET raised the toughness from 61.55 HD (at 4.5 %) to 80.3 HD (at 13.6 percent). However, at 18 percent PET, hardness dropped to 68.25 HD of the sample. The results suggested that PETimproves the composite's attaching power.At 18.0 percent of PET, however, the matrix and PET detached, reduced the hardening of such composite parts.

The stripping process is used to calculate the amount of bitumen lost from a sample of asphalt. The rate of stripping declined as the PET weight percent rose.During 72 hours of immersion, the 13.6 percent and 18 percent bitumen coated aggregates with PET showed no signs of stripping. Within 72 hours, the mixture of aggregate and bitumen lost mass of 2g (a 3.3 percent loss). Furthermore, the non-porous aspect of PET improved water resistance, demonstratingnegligible degradation in samples. Consequently, the improved composite samples are expected to remain intact for a longer time, decreasing the number of potholes on highways. This will also lower building costs by lowering costs of maintenance and the total construction cost [15].

C. Test of Flow and Marshall Stability

Higher value of Marshall Stability indicates the mixture of stronger strength. Marshall Stability value improved as the amount of plastic applied is increased. The percentage of plastic used was raised from 10% to 30%, then to 50%. The values climbed from 21.0 to 23.8 and then to 26.3, in that order. All of these values were better than the control values, which came in at 15.1. The values 6.6, 8.2, 9.8, and 4.2 were the flow values assigned to them, respectively. The percentages of voids are also respectively 10.02, 12.33, 14.93, and 5.31. The experiment used aggregatesof size ranging from 0 to 14millimeters that are suggested by the Ghana Highways Authority for use as the wearing course in road building. For wearing course, Marshall Stability value is recommended between 9 to 18, while the percentage voids and the flow are 3-5 and 2 to 4, respectively. For Dense Bitumen Macadam, the normal Marshall Stability values are 8.2–18, while flow and percentage voids are 2–4 and 4–8, respectively. Air void values obtained in the experiment are very similar to those obtained in the DBM.With inclusion of 10 percent plastic, the values of Marshall Stability yielded findings that were similar to the standard values, while Marshall Stability values with higher percentages of plastic wastes were not close to the standard. This may be by adding plastic waste to aggregates expands aggregate sizes from 0–14 mm to about 0–40 mm [10]

D. Los Angeles Abrasion Test on Plastic Coated Aggregates

When comparing the Plastic Coated Aggregates to control sample, the findings of the Los Angeles Abrasion experiment revealed improved accuracy. Aggregate percentage that was subjected to wear and tear decreased from 25% to 18%, compared to a minimum of less than 30%. The Plastic coated aggregates,18 percent LAA rating indicates that the plastic used to cover the aggregates made it thicker than it was before, allowing it to withstand abrasion from steel balls[10]

E. Penetration and Softening Point

The specimen prepared by wet process demonstrated a penetration value of 88.03dmm for high density poly ethylene (HDPE) as compared to 104.3dmm for base bitumen. Further, the softening point of HDPE showed linear increase by using 3% plastic waste. It also increased the viscosity of the bitumen significantly[2].

F. Flexural and Compression properties

The sample of the PET was cleaned, thoroughly dusted, brushed, and sun-dried after it was picked. This dry waste plastic was grinded. Preheating of quartz aggregates was done at 170°C, and shredded product of size range 2.3-2.7 mm was added to the previously heated aggregates at designated proportions (0%, 4.5%, 9.0 %, 13.6%, and 18.0% PET). To ensure consistent delivery of the plastic, the process was constantly mixed. After that, Bitumen was applied to the samples at a 140 °C - 160 °C after aggregates were completely coated with PET. Before putting the sample into cylindrical and rectangular moulds, the mixtures were thoroughly mixed. The compressive pressure increased steadily from 1.64 MPa to 7.42 MPa for the 13.6 percent sample. However, at 18.0 percent, with 0.75 MPa value of compressive strength, an unexplained drop in compressive strength was found. The efficient bonding between the two phases is reduced as saturation of PET occurs in the matrix of bitumen. As a result, there were fewer correlations between PET-aggregate/PET-bitumen.

Similarly, elasticity modulus for test sample and at 13.0 percent was 10.9 MPa and 123.67 MPa respectively, before dropping to 10.7 MPa when PET percent was 18 due to saturated PET in asphalt. The composites flexural modulus was highest at 18.0 percent and 13.6 percent PET. Reinforcing a matrix is all about repairing pre exiting fractures.Because of the inadequate interaction among the matrix and reinforced phase, that influences the materials' mechanical properties, an inadequate reinforced phase cannot greatly control micro cracks. PET material was increased to some degree, which improved the performance (13.6 percent PET). Owing to poor bonding among the various phases exiting, an uninterrupted rise in PET above 13.6 percent PET like at 18 percent,was unable to control micro-cracks and thus decreased the flexural and compressive properties of the matrix.

In general, the composites created could withstand higher compressive loads as compared to those applied in a direction which is flexural. This is due to the fact that the area of the specimen expands during compression,

ISBN: 978-93-91355-11-1

requiring more stress to distort. As a result, increasing the cross-sectional area gradually raises the load-bearing capacity. Similarly, in compression, the pressure at which loss occurs is greater than in bending [15].

VI. Performance of Roads

The pothole, cracking, rut depth mm using 3m straight edge and ravelling capacity of the plastic roads was found to be significantly less than the conventional roads in study conducted on roads with similar environmental conditions and construction periodin an area of 10-12km in Pune city of India by Biswas et al. [16].

VII. Maintenance

The plastic modified bitumen roads need repair after 10 years in comparison to the roads constructed using conventional material which usually require repair after 5 years. However, the overall effect of traffic load was not reported in this study by Centre for Innovation in Public Systems.

VIII. Health and Environmental Hazards

A study conducted by White et al. [17], reported that the leachate and toxic fumes resulting due to the plastic roads were negligible.

IX. Waste Plastic and Commercially Produced Polymers

Waste Plastic utilized to modify asphalt demonstrated similar resistance to rutting and enhanced fatigue life when compared with the commercially manufactured polymers employed to modify the bitumen [18].

X. Conclusions

The utilization of the waste plastic material in the highways results in the better quality as well as economical roads along with safe disposal of the non-biodegradable waste material. These roads prove suitable from the maintenance aspect. The proportion of the binder material reduces significantly. PET is a waste plastic product in our surroundings that has been transformed into building materials. PET was combined with bitumen and coarse aggregates to improve the resilience of bitumen composites. The stripping test method was used to investigate corrosion through mass loss. Following all of the checks, the sample containing 13.6 percent poly-ethylene-tetraphylatedemonstrated the required properties, including greater elastic modulus and increased compressive strength.The flexural power and flexural modulus, as well as the modulus of stability and hardness, were all higher in this same composition. Lowerobservationsfor stripping at 13.5 percent indicate corrosion resistance of the material.The main consequence of this finding is that PET may be used to boost road building by complementing bitumen. As the structures presented are more resistant to water absorption, this will result in reduction of the road maintenance cost while also improving the shelf-life of highways. In addition, this practice resulted in increased softening point, improved hardness and stripping, lower impact and crushing value of the bitumen matrix. In Indiathere are limited resources and the bituminous roads require efficient maintenance year after year, the introduction of plastic roads will save local governments a lot of money on pre-monsoon city road maintenance. The waste plastic utilization to replace bitumen would proveeconomicalin comparison to expensive bitumen, making these roads much more useful. Furthermore, successful use of plastic wastein the modified bitumen preparation would result in a significant rise in the salvage value that would on the other hand be unwantedgarbage scattered in urban areas. The studies have shown that plastic waste could have similar effects in asphalt modification to commercially produced polymers with high rutting strength, a more elastic behavior that increases fatigue life and cost-effective benefit.

The future studies can be conducted on the utilization of plastic waste in base, sub base or subgrade layers of the flexible pavements. Further, a detailed research is essential to analyze the effect of plastic leachate used in the pavement.

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 ISBN: 978-93-91355-11-1