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Experimental investigation of waste plastic bottles as partial replacement of aggregates in flexible pavements

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ABSTRACT

Global plastic pollution reported that; 1 million plastic bottles bought every minute, 100,000 marine animals killed by plastic each year, 500 years to degrade in the environment, 90% of bottled water contain plastic particles. Ethiopia is facing rapid urbanization and industrialization leading to the packing of different industrial products with plastic bottles which finally becomes waste and on the other side, pavements are behaving different structural failure and surface defects before the end of the construction period and service year.

In order to minimize the above serious problems, this research was initiated to do an experimental investigation of the waste plastic bottle as partial replacement of aggregate in the bituminous concrete mix through the dry process to enhance the desired performance of bitumen concrete mix and to reduce plastic bottles disposal problem. Before applying PET bottles as additives, optimum bitumen content was determined for conventional bitumen concrete mix which is selected as 5.33%; upon which the effect of PET bottles experimented. Waste plastic bottles are collected and cut into pieces using scissors. Then it was melted in the oven at 180^{0}c for 30 minutes. Then after cooling down, it was pulverized. Finally weighing the required amount of pulverized plastic and replacing the aggregate by 0%, 4%, 6%, 8% and 10% by weight of aggregate, the marshal test was held and volumetric properties on each specimen were computed.

Based on the laboratory result, the optimum plastic content was selected at the specimens that have high stability; high bulk density and minimum air void values are 20.66 KN, 2.59gm/cm3 and 3.25% respectively. The optimum plastic content is selected at 4% of the plastic bottle by weight of aggregate. Lastly, this study concluded that partial replacement of aggregate by the waste plastic bottle can increase the overall performance of bitumen concrete mix.

Finally, this study recommends it is better to apply this new construction technology on the ground and to adopt it. It is better to know the cost-benefit analysis on partial replacement of aggregate by waste plastic bottles in flexible pavements.

Keywords— *Bitumen Concrete, Modified Bitumen, Optimum Binder Content, Optimum Plastic Content, Plain Bitumen*

1. INTRODUCTION

Bituminous concrete is one of the widely used and costliest types of flexible pavement layer used in the surface course. Properties of a good bituminous mix are skid resistance, stability, durability etc. The mix design should aim at economical blends with the proper gradation of aggregate and an adequate proportion of bitumen so as to fulfil the desired properties of the mix. Marshall Stability test is conducted on compacted cylindrical moulds of bituminous mix to determine the optimum binder content (Jadon, 2016).

Semi-dense bituminous concrete is the most commonly used pavement material due to its construction procedures. The ever increasing economic cost and scarcity of availability of natural material have opened the opportunity to explore locally available waste material. If industrial waste materials can be suitably used in road construction, pollution and disposal problems may be partially reduced (Fatima, Sahu, Jhamb, & Kumar, 2014). Utilization of waste material as secondary material is being developed worldwide. One of these waste materials is plastic bottles which are being accessible in the large amount. In food industries, the plastic bottle is mostly made by Polyethylene Terephthalate (PET). PET becomes very popular during the last decade because it is known as safe, durable and good material for packaging (Moghaddam, Karim, & Soltani, 2013). The threat of disposal of plastic will not be solved until the practical steps are not initiated at the ground level. It is possible to improve the performance of bituminous mix used in the surfacing course of roads. Studies reported that the use of recycled plastic, mainly polyethene, in the manufacture of blended indicated reduced permanent deformation in the form of rutting and reduced low temperature cracking of the pavement surfacing. The field tests proved that plastic wastes used after proper processing as an additive on flexible pavement would enhance the life of the pavement and also solve environmental problems (Gawande, Zamare, Renge, Tayde, & Bharsakale, 2012). Plastic and tyre is a non-biodegradable material. Despite, the quantum of plastic waste is also increasing day by day which is hazardous to our health. Thus using plastic waste for construction purpose of flexible pavements will be one of the alternatives for disposing of them in an eco-friendly manner (Deshmukh, Kendre, Chaudhari, Hirve, & Shinde, 2015).

2. LITERATURE REVIEW

The benefits of using waste materials like fly ash and plastic waste are considerable reduction in the use of natural raw materials, responsible for industrial sustainability, solves the disposal problems of wastes as these are utilized in construction activities, plastic improves some properties of bituminous mixes used for paving roads (Mishra & Gupta, 2017).

In order to withstand tyre and weather, pavement surface layers contain the strongest and most expensive materials in road structures. Characteristics they exhibit like friction, strength, noise and ability to drain off surface water are essential to vehicles" safety and riding quality (Huang, Bird, & Heidrich, 2007).

2.1 MATERIALS IN BITUMEN CONCRETE MIX

Aggregate is a major component of asphalt mixes, so their properties play a significant role on the asphalt paving mixtures. An aggregate gradation that yields maximum solid density and maximum particle interlock are highly desirable for the asphalt concrete mixes. Maximum particle interlock leads to high mix density and stability. While minimum voids in a certain material composition lead to high strength (Serag & Kamash, 2014).

Aggregate is the major structural framework of asphalt mixture to absorb and control different stresses on the pavement. Mineral aggregates make up 90 to 96% of an HMA mix by weight or approximately 75 to 85% by volume. Gradation is one of the important characteristics of aggregates affecting permanent deformation of hot mix asphalt. The asphalt contents of the mixes were maintained at the job mix design contents. Properties investigated were Marshall Stability, Marshall Flow, unit weight, air voids, and voids in mineral aggregate (Deepesh Kumar Singh Lodhi, 2016).

Aggregates without plastic and aggregates coated with waste plastic equal to 0.5%, 0.55%, and 0.6% of the weight of dry aggregates. The use of plastic waste in the construction of flexible pavement is one of the best methods for the safe disposal and better performance of the bituminous mix if plastic coated aggregates are used (Singh & Yadav, 2016).

OBC for conventional SMA, BC and DBM mixes are found as 6%, 4.5% and 4.5%. Similarly, OBC is found as 4% for modified SMA, BC and DBM mixes with polyethylene at different concentration. With the addition of polyethylene, stability value also increases up to certain limits and further addition decreases the stability. This may be due to an excess amount of polyethylene which is not able to mix in asphalt properly. Optimum polyethylene content (OPC) which is found as 2% for SMA and 1.5% for DBM bitumen mixes (Panda, Prusty, & Chattaraj, 2013).

2.2 WASTE PLASTIC BOTTLE

Polymers can be broadly classified as either thermoplastics (“linear”) or thermosets (“cross-linked”). Thermoplastics have only secondary bonds between chains, while thermosets also have primary bonds between chains. Thermoplastic polymers can be melted or molded while thermosetting polymers cannot be melted or molded. The triangle, in the recycle code of plastic, indicates that the plastic material is recyclable, and each number inside the triangle indicates a specific type of plastic (Pavani & Rajeswari, 2014). 90% of bottled water found to contain plastic particles, 83% of tap water found to contain microplastic particles, 50% of consumer plastics are single-use, 10% of all human-generated waste is plastic. In the next 10-15 years, global plastic production is projected to nearly double (Day, 2018).

The use of PCA (plastic coated aggregate) for asphalt pavement helps for the reuse of plastics waste and for the improvement of road strength. The littered plastics, a non-biodegradable material, get mixed with domestic waste and make the disposal of municipal solid waste difficult. The municipal solid waste is either incinerated or used for landfill. Both are not the right techniques to dispose of the waste and it will create both land and air pollution. This process helps to dispose of the waste by eco-friendly method (Vasudevan, Ramalinga Chandra Sekar, Sundarakannan, & Velkennedy, 2012).

The large volume of composite materials required for the construction and maintenance of road pavements in the UK is potentially a major area for the reuse of waste materials. Because the amount of new materials like mineral aggregates required in the road construction industry is large, approximately 20,000 t per mile of motorway constructed, the environmental benefits are not only related to the safe disposal of bulk waste but also to the reduction of environmental impacts arising from the extraction of aggregates which include the loss of mature countryside, visual intrusion, heavy lorry traffic on unsuitable roads, noise, dust and blasting vibration (Zoorob & Suparma, 2000).

The performance of PET as an aggregate replacement had been done in concrete technology. The usage of waste PET granules pellet experimented as a partial fine aggregate replacement in asphalt mixture. According to the Waste and Resources Action Program (WRAP) survey, most plastics collected for recycling from the household waste stream are plastic bottles [16]. Plastics having a variety of properties are available at present. They have low specific gravities, ease of fabrication, resistance to low thermal and electrical conductivities (Pavani & Rajeswari, 2014). In order to, provide appropriate plastic particles the bottles were cut to small parts then crushed and sieved. The particles which were smaller than 2.36 mm were considered for this investigation.

It should be noticed that different percentages of crushed plastic bottled were designated for this study namely: 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1 % by weight of aggregate particles (Moghaddam et al., 2013).

The production rate of plastic is getting increased day by day in all parts of the world since the past few decades. Due to the tremendous growth in population, consumerism, industrialization and technological development, there has been a rapid increase in the rate of the production of plastic which is a toxic persistent material (Vootukuri & B., 2018). Addis Ababa, the capital city of Ethiopia suffers from poor solid waste management. The inadequate solid waste management system has rendered development, lessened the aesthetic beauty of the city and most importantly endangered the lives of the people. Regard-less of the harmfulness of the waste, solid waste management has not been given the amount of attention it requires. The insufficient management and lack of attention to the matter can be observed from the unbearable litter in the rivers, drains and streets in Addis Ababa. It is obvious that immediate action is needed in the solid waste management sector (Cheru, 2016).

The daily SW generation rate of Sodo town for low-income, middle and high-income was 28 kg/capita/day, 0.38 kg/capita/day 0.76 kg/capita/day, respectively. This indicates that the waste generation rate of higher-income was about 2.7 times higher than lower income. The average SW generated in Sodo town is estimated to be 0.47 kg/capita/day; 14.2 Kg/capita/month 170.4Kg/capita/year. This generation rate is higher when compared with study findings of comparable major Ethiopian towns (Goa & Sota, 2017).

Hot stone aggregate (150ºc) is mixed with hot bitumen (170ºc). The aggregate, when coated with plastics and rubber improved its quality with respect to voids, moisture absorption and soundness. The coating of plastic and rubber decreases the porosity and helps to improve the quality of the aggregate and its performance in the flexible pavement (Wayal & Wagle, 2013). Thermo gravimetric analysis has shown that there is no gas evolution in the temperature range of 130-180°C. Moreover, the softened plastics have a binding property (Global environment facility, 2017). Here waste plastic was used as modifiers added on the aggregate before mixing Optimum Binder Content (OBC) in dry process at a 150-160ºC temperature which increases the bonding between aggregates coated with plastic which increases the strength of the bituminous concrete mixes. Stability values and indirect tensile strength values were observed to be more in polymer modified bitumen than in conventional bitumen (Pavani & Rajeswari, 2014). The mechanical properties obtained from the Marshall Stability and Flow value. Marshall Stability indicates the maximum load that a sample can carry when being tested at 60°C, and Marshall Flow is the deformation that a sample undergoes during loading until the maximum load is reached. An increase in the Marshall Stability value indicates an improvement in the stability of an asphalt mixture to resist shoving and rutting under heavy traffic load (Zakaria et al., 2018).

2.3 PLASTIC AS AN AGGREGATE

Recycled LDPE can substitute a portion between 15 and 30% of aggregates depending on its particle size (Huang et al., 2007). The polymer material is coated over stone aggregate (plastic coated aggregate) is used as a raw material for pavement construction. The PCA is mixed with bitumen and the mix is used for flexible pavement construction. The higher percentage of plastic waste (10–15%) can be used without separation. Most of the packing materials can be shredded and used for road construction. The waste plastics namely films, cups and foams shredded to the required size of 2.5–4.36 mm. The aggregate is heated to 170 ºC. Plastics got softened and coated over the aggregate. The extent of the coating was varied by using different percentage of plastics. The shredded plastics on spraying over the hot aggregate get melted and spread over the aggregate giving a thin coating at the surface. When the aggregate temperature is around 140–160 ºC the coated plastics remain in the softened state. Over this, hot bitumen (160 ºC) is added. The added bitumen spreads over the aggregate. At this temperature both the coated plastics and bitumen are in the liquid state, capable of easy diffusion at the interphase. This process is further helped by the increase in the contact area (increased surface area). Use of plastic as virgin as well as waste to modify the bitumen and also the use of PCA are being studied to find better results for the better performance of the pavement (Vasudevan et al., 2012). Intending to minimize the dependence on the supply of stone aggregate, it has become essential to inspect the possible applications of alternative materials for the construction of roads as a substitute of stone aggregate (Zachariah, Sarkar, Debnath, & Pal, 2018).

Recycled waste plastics, predominantly composed of low-density polyethylene (LDPE) in pellet form, were used in dense graded bituminous mixes to replace (by volume) a portion of the mineral aggregates of an equal size, i.e., 5.00-2.36 mm. Based on the selected AC grading and the size of the waste plastic pellets, a maximum of 29.7% by weight of the total control mix were replaced with waste plastics. The main variable between the Plastiphalt and the control AC mix would, therefore, be the bulk density of the combined aggregate fractions. Laboratory design methodology and test results of a continuously graded bituminous composite Asphaltic concrete (AC) containing recycled plastics aggregate replacement are called (Plastiphalt). Softer bitumen was selected for the Plastiphalt because early trials indicated that the mix was very strong and did not require the use of hard bitumen. This has added advantage that the mixing and compaction temperatures of the bituminous mix, which are controlled by the viscosity of the binder, can thus be lowered (Zoorob & Suparma, 2000). XLPE waste as an aggregate with several volume percentages was utilized to replace the natural coarse aggregate of concrete mix. This replacement was conducted with 5%, 15%, 30% and 50% contents (Shamsaei, Aghayan, & Kazemi, 2017)

The modified asphalt mixtures were produced from the content concentrate of recycled PET pallet range between 5 and 25% of the weight of asphalt mixture with sieve size from 2.36mm to 1.18mm and 5% weight of bitumen content as follow hot mix asphalt wearing course 14 (ACW14) in Standard Specification of Road Work in Malaysia. It was tested to use waste plastic bags by conversion into a recycled plastic waste aggregate (RPWA) in asphalt mixture. Then this asphalt modified mixture was developed using 20mm aggregation gradation. The 1200g / 3800g of aggregate containing RPWA in proportion from 0 to 15 per cent by weight of total aggregate was used to produce Marshall Sample. RPWA can be added in asphalt mixture up to 2.5% by total weight of the aggregate (or up to 6% on the volumetric basis). RPWA could be applied both in the surface course and base course of pavement. This material substitute aggregate sieve size from 3.35mm to 14mm because their size is 2mm diameter. The optimum bitumen content of control asphalt mixture was determined from bitumen content ranges from 4 to 6% of the weight of asphalt mixture. Then the bitumen and aggregate were compacted at temperature 150⁰c with 75 blows each surface by Marshall Compactor. The usage of waste PET granules pellet experimented as a partial fine aggregate replacement in asphalt mixture. The size of this material is 3mm. The asphalt mixture was produced from 60/70 penetration grade bitumen and 12.5mm aggregate grading (Rahman & Wahab, 2013).

The first step is the collection of materials which include Plastic wastes such as, Milk pouches, Polythene bags, water bottles. We must make sure that there are no dirt particles on the plastics which are going to be used. Thus cleaning of the wastes must be done to avoid degradation. The collected items must be shredded to 4-5mm size. This can be achieved by the employment of a shredding machine. We for testing have cut plastic manually. Partial replacement of fine aggregate is done in different proportions such as 15%, 20%, 30%, 40% and 50 % (Pooja, Vaitla, Sravan, Reddy, & Bhagyawati, 2019).

Meanwhile, utilization of waste plastic bags in asphalt mixture around the world, especially in developed countries, has proved that these enhance the properties of the mixture in addition to solving disposal problems including Polyethylene Terephthalate (PET), which is a type of plastic bottles in conventional life. Plastic waste is cleaned and cut into two types, i.e. fibrous and fine. The aggregate mix is heated and the plastic is effectively coated over the aggregate. This plastic waste coated aggregate is mixed with hot bitumen and the resulted mix is used for pavement construction. Before Marshall Test, all samples have to be placed in a water bath for 40 minutes at a temperature of 60⁰C. The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. The flow value is the deformation corresponding to the Marshall Stability (Huy & Tuan, 2011).

2.4 PREPARATION OF SAMPLE

The required quantities of course aggregates, fine aggregates & fillers were taken in an iron pan and kept in an oven at a temperature of 160°C for about 2 hours. The aggregates in the pan were heated at 160°C for a few minutes and then the required amount of shredded polythene was weighed and added to aggregates and mixed for 2 minutes. Next, bitumen was added to mix and the whole mix was stirred for 15-20 minutes to make a proper uniform and homogenous mix (Chaubey, 2016) The blending of recycled LDPE to asphalt mixtures required no modification to existing plant facilities or technology (Huang et al., 2007).

This PCA mix was then mixed with a known quantity of 80/100 bitumen. The specimens (64 mm height and 102 mm diameter) were prepared by, varying the percentage of plastics waste and by varying bitumen quantity. Samples of 101.6 mm diameter and 63.5 mm height were prepared using moulds of 101.6 mm diameter and 76.2 mm height. For compaction of the samples, a compaction hammer of weight 4.53 kg and a free fall height of 457 mm were used. Preliminary studies indicated that, for mixtures incorporating polypropylene fibers, the mixing temperature was less than 140⁰C (Zachariah et al., 2018).

The experimental mixtures were manufactured at five different bitumen contents. The Leeds design method was then used to obtain the optimum bitumen content of the design mixture. At optimum bitumen content, further investigations and tests were carried out to fully characterize the properties of the design mixture. The mixing and compaction temperatures need to be carefully controlled to cater for the differing softening points of the two plastic types. At worse, with minimal temperature control, the plastics behave as inert aggregates contributing to the continuation of the mineral aggregate interlock. The Marshall test is an empirical test in which cylindrical compacted specimens, 100 mm diameter by approximately 63.5 mm high are immersed in water at 60°C for 30-40 min and then loaded to failure using curved steel loading plates along a diameter at a constant rate of compression of 51 mm/min. The LDM recommends that the optimum bitumen content for dense-graded mixtures should be obtained as the arithmetic means of the optimum bitumen content at maximum compacted mix density, minimum voids in the mineral aggregate (VMA), and maximum stability. The MQ (kN/mm) values are defined as the ratio of Marshall Stability (kN) to flow (mm) (Zoorob & Suparma, 2000).

2.5 TESTS TO BE CONDUCTED AND FINDINGS OF PREVIOUS STUDIES

Marshall Stability value increases with polythene content up to 4% and then decreases. The addition of polythene decreases the Marshall Flow value. This shows the resistance to deformation under heavy wheel loads keeping the value of parameter like VMA, VA, VFB is within the required specification. In India where temperature rises up to 50°C, this adversely affects the life of the pavement. In the modification process, plastic waste is coated over aggregate which increases the surface area of contact and ensures better bonding between aggregate and bitumen (Chaubey, 2016).

With an increase in binder content, VFB value is increasing. Also as the proportion of plastic increase the VFB value increase as compared to that of the conventional mix. The bulk density of the mix is increasing with the increase in binder content up to a certain binder content which is OBC and then it starts decreasing. The values of bulk density are decreasing with an increase in waste plastic content. With Increase in binder content, air voids are decreasing but the value decreases with an increase in plastic waste content. With an increase in binder content, VMA is also increasing. With the Addition of plastic, VMA values are increasing to that of convention mix. Flow value increases as an increase in binder content but with the addition of plastic waste, its values are less than that of conventional values. Its value is increasing with the addition of plastic content (Jadon, 2016).

An asphalt paving mixture is a multiphase composite material that consists of an asphalt binder, coarse aggregate, fine aggregate, mineral filler, and other additives. The behavior of an asphalt mixture is highly related to the volumetric fractions and space distribution of these components. Air void is one of the most important volumetric properties of an asphalt mixture that affects the mixture's stability and durability. An asphalt mixture with lower than optimum air voids may cause rutting due to plastic flow, whereas higher air voids can result in premature cracking or ravelling due to moistures and oxidation (Chen, Huang, & Shu, 2013). By using Marshall Stability and Flow test, the result shows that the aggregate replacement of 20% fine aggregate (2.36-4.75mm) by volume with PET granulates (5% total weight of the asphalt mixture) was the effective use to get the highest Marshall Quotient with the lowest flow and the highest of stability. The usage of waste PET granules pellet was conducted as a partial fine aggregate replacement in asphalt mixture. The 80/100 penetration grade bitumen, crushed granite, Portland cement (as mineral filler) and the waste PET were used in their project. The percentage of the added PET in this research was from 0 to 10% by weight of bitumen. The size of this material is 3mm (Rahman & Wahab, 2013).

Marshall Stability value is the basic study on the stability of the mix with the application of load. The aggregate mix was coated with plastics waste. This PCA mix was then mixed with a known quantity of 80/100 bitumen. Marshal Stability Value is indicative of the load withstanding property of the flexible pavement (Vasudevan et al., 2012). The Marshall test is used widely throughout the world to determine the stability and flow characteristics of bituminous mixes. In this method, the resistance to plastic deformation of a compacted cylindrical specimen of the bituminous mixture is measured when the specimen is loaded diametrically until its failure (Chaubey, 2016).

Similar to tyre rubber, recycled plastics can either replace a portion of aggregates or serve as a binder modifier. DBM with recycled plastics, mainly low-density polyethylene (LDPE) replacing 30% of 2.36–5mm aggregates, reduced the mix density by 16% and showed a 250% increase in Marshall Stability in the ‘’Plastiphalt’’ mixtures. Recycled LDPE of a size between 0.30 and 0.92mm replacing 15% aggregates in asphalt surfacing nearly doubled the Marshall quotient, and increased the stability retained by 15%. Recycled PE accounting for 8% of the binder as a bitumen modifier, can also increase the mixture’s Marshall Stability (Huang et al., 2007).

It was found that there is a significant improvement in the strength properties of the plain aggregate with a coating of polymers. When the polymer was coated over the aggregate, the aggregate surface is covered with the thin film of polymer, then it fills the pores at the surface and there is no water absorption (non-wetting when exposed to water and moisture). The performance of plastic tar road conclusively proves that it is good for heavy traffic due to better binding, increased strength and better surface condition for a prolonged period of exposure to variation in climatic changes. Above all, the process helps to dispose of waste plastics usefully and easily. There are so many advantages including increase the strength and performance of the road, avoid the use of anti-stripping agents, reduce the cost to around Rs. 30,000/km of single lane road as on date, carry the process in situ, avoid industrial involvement, avoid disposal of plastics waste by incineration and landfilling, generate jobs for rag pickers, add value to plastics waste and develop a technology, which is eco-friendly. Waste plastics, littered both by domestic and industrial sectors were found to be a source of raw material for the flexible pavement. Waste plastics, mainly used for packing are made up of PE, PP and PS, their softening point varies between 110ºC and 140ºC and they do not produce any toxic gases during softening. After sprayed over the hot aggregate at 160ºC, PCA was then mixed with hot bitumen of different types. The sample showed higher Marshall Stability value in the range of 18–20 KN and the load-bearing capacity of the road is increased by 100% and there is no pothole formation. The roads laid since 2002 using PCA + bitumen mixes are performing well. The ratio of MSV and FV (referred to as Marshall Quotient) should be no more than 500.

The results obtained for the PCA are within this range. Voids filled with bitumen (VFB) are expected around 65% and the observed value is around 58%. The reduction is attributed to the reduction in the use of a percentage of bitumen (90%) and the reduction in voids. The use of plastics waste coated aggregate; the quantity of bitumen needed for a good mix can be reduced by 0.5% of the total weight. This accounts for a 10% reduction in the quantity of bitumen needed to be used. A higher percentage of plastics (more than 15%) results in lesser compatibility with bitumen and lesser bonding resulting in lower MSV. The use of PP gives higher MSV value than PE. The foams of PP and PE also give better MSV results. The flow value and the voids filled with bitumen are within the tolerance value. It is observed that the values of the PCA bitumen mix are 50– 60% higher than that of the PMB mix. When bitumen was mixed with PCA, the portion of bitumen diffuses through the plastic layer and binds with aggregate, then three-dimensional internal cross-linked network structure results between polymer molecules and bitumen constitute. Therefore the bonding becomes stronger and the removal of bonded bitumen becomes difficult. The dry process showed that the bonding between stone aggregate and bitumen is improved due to the presence of polymers (Vasudevan et al., 2012).

The unit weight of the fiber-reinforced specimens is lower than that of plain specimens and the volume of air voids increased with increase in the content of polypropylene fibers along with significant improvement in stability and flow values. They blended fibers with aggregates at the optimized dosage of bitumen rather than conventional procedures. Adding polypropylene fiber increases the Marshall stability by 26% and the air voids by 67% while reducing the flow properties by 38% (Shamsaei et al., 2017).

At the same air-void content, the compacted Plastiphalt mix has lower bulk density than that of the conventional control mix. A 30% aggregate replacement by volume with the LDPE of single size (5-2.36 mm), with aggregate of the same size, results in a reduction in bulk compacted mix density of 16% and 250% times increase in the Marshall Stability (strength) value and an improved Marshall Quotient value (resistance to deformation) and higher flow value than the control mix due to the more flexible plastic component of the mix. This reduction in density is advantageous in terms of haulage costs. The aggregate gradation of the resultant Plastiphalt mix would, therefore, be very similar in terms of volumetric proportions to the original AC control mix. This strength can be achieved because the Plastiphalt is mixed and compacted at the correct preselected temperatures. Although the stability value of the Plastiphalt mix at OBC may at first instance seem unrealistically high, it must be noted that recent advancements in bituminous mix design have created very high-performance mixtures. Conventional dense-graded mixes normally combine high stability with low flow values and hence high MQ values indicating a high stiffness mix with a greater ability to spread the applied load and resist creep deformation (Zoorob & Suparma, 2000).

The aggregate replacement of 20% fine aggregate (2.36-4.75mm) by volume with PET granulates (5% total weight of the asphalt mixture) was the effective use to get the highest Marshall Quotient. The ACW14 recommends that the optimum bitumen content should be obtained range 3 to 5% air void, 65 to 78% void filled with bitumen and 14 to 15% void mineral aggregate (VMA). It was tested to use waste plastic bags by conversion into a recycled plastic waste aggregate (RPWA) in asphalt mixture. RPWA could be applied both in the surface course and base course of pavement. The optimum bitumen content of control asphalt mixture was determined from bitumen content ranges from 4 to 6 by Marshall Compactor.

The result indicates that the optimum bitumen content of the control sample is 5% of the mass of asphalt mixture. The lab testing reveals the maximum permanent deformation at 20% replacement with recycled PET. In term of economic value, it shows that this recycled PET could reduce the cost of road construction because this recycled material is cheaper (Rahman & Wahab, 2013).

Using of waste plastic and/or waste rubber in hot aggregate forms a coating around the aggregate. When these aggregates are mixed with bitumen, the mixture is found to give higher strength, durability and better waterproofing properties. Some of the major objectives of the study are to analyze the effect of plastic and rubber waste on Stability-Flow & Volumetric characteristics of Bituminous Concrete Mix and to develop binary and tertiary Bituminous Concrete mix having better engineering properties than Controlled Mix (Bansal, Kumar Misra, & Bajpai, 2017).

The more asphalt and PET content increase, the more the Marshall Stability decrease. With the same asphalt content, the samples without PET have Marshall Stability lower than ones using PET. Asphalt mixture with fine type is better than one with fibrous type in terms of Marshall Stability. Fine PET mixture could be a promising material in comparing with fibrous PET in this study. PET is a type of thermoplastic, belongs to polyester family. It was cleaned and cut into two forms such as fibrous type 30x1.5mm and 1.5x1.5mm that used in asphalt concrete (Chaubey, 2016).

The optimum bitumen content for the Plastiphalt mix was determined at 6.0%. The compacted densities of the Plastiphalt mixes were lower than that of the control mix. A 29.7% coarse aggregate replacement by volume with the lower specific gravity LDPE, results in a 16% reduction in bulk density of the compacted mix which is accompanied by a reduction in the VMA, which indicates a tighter, denser aggregate skeleton. A stability increase of nearly 2.5 times indicates that the Marshall Stability value of controlled mix (6% by weight of aggregate) is 9.06 KN.

The maximum stability value was obtained for BM9 (84%B + 6%P + 10%R), followed by BM6 (90%B + 10%R) and BM3 (92%B + 8% P). The stability value BM9 (53%), BM6 (45%) and BM3 (16%) are significantly higher than the non-modified mix. Flow value of bituminous mixes is found to be increasing in each series with an increase in percentage replacement by waste additives. Flow value of non-modified mix is 3.8 mm, while BM9 is 3.9 mm, BM3 (3.35 mm) and BM6 (3.7 mm) is also within the specified limit. Exceptionally high flow values are observed for the mixes containing greater than 10% replacement of rubber content. Bulk density of non-modified mix is 2.320 g/cc, 2.362 g/cc (BM3) for 8% replacement of bitumen by waste plastic and while the maximum value of around 2.328 g/cc was achieved at (BM6) for 10% replacement of bitumen by waste rubber.

Maximum density obtained was found to be 2.331 g/cc (BM9) for 16% replacement of bitumen by the combination of waste plastic (6%) and rubber (10%). All these values were found to be higher than the density of the non-modified mix. Air voids in the non-modified BC mix were found to be 3.72%, which is well within the allowable limits. Overall air voids percentage escalates with an escalation in the partial replacement percentage of waste materials with bitumen in all modified mixes. This is due to variation in density of waste additives blended in BC design. Voids in the mineral aggregate are found to be 12.07% in non-modified mix, which is well within the specified limits that depend upon the nominal maximum size of aggregate and design air voids. Overall voids in mineral aggregate escalate with an escalation in the partial replacement percentage of waste additives in all three modified mixes (Bansal et al., 2017).

2.6 DETERMINATION OF OPTIMUM PLASTIC CONTENT

To determine the optimum fiber content, the average of the following three fiber content is taken: the fiber content corresponding to maximum stability values, the fiber content corresponding to maximum unit weight, the fiber content corresponding to the median of the percentage of air voids in the total mix. The addition of PP fibers to bituminous mixtures increased the Marshall Stability value, decreased the flow value a fiber content of 5.33%, a binder content of 4.83% provide good stability volumetric properties [30]. (Mathew & Babu, 2015) The optimum modifier content is 12 % by weight of bitumen, polyethylene modified asphalt mixtures reduce permanent deformation, raise fatigue resistance and give better bond between the bitumen and the aggregates [32]. (Kamran Muzaffar Khan et al., 2013).

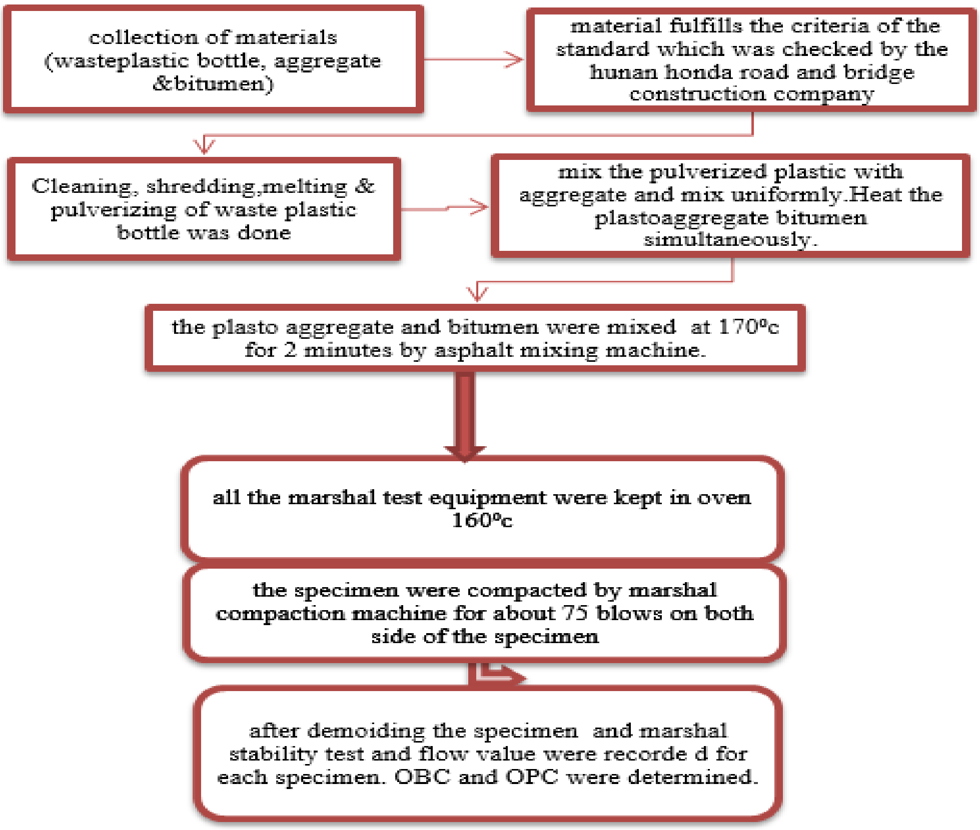
2.7 DETERMINATION OF OPTIMUM BITUMEN CONTENT

To determine optimum binder content, marshal specimens are prepared for bitumen content varying from 3.5-6.0% of the blended aggregates at an interval of 0.5%. The marshal stability value, flow value, unit weight and VFB are evaluated. Based on the graphs obtained, the optimum binder content is decided (K, 2012).

3. RESEARCH DESIGN

Experimental research was applied in this study area of the research; the required materials for this research work were collected such as waste plastic bottle, aggregate and bitumen. Testing of materials was held by the Hunan Huanda road and bridge

Construction Company in order to check the materials (aggregate and bitumen) physical properties whether/not they fulfil the requirements as standard specifications. The mix was held through the dry process since it is difficult to attain uniform mix in the wet process.



3.1 AGGREGATE GRADATION

Aggregate gradation analysis and the combining of aggregates to obtain the desired gradation are important steps in hot mix asphalt design. The aggregate gradations met the gradation requirements and yield a mix design that meets the criteria of the mix design method. To determining the proportion of aggregates to achieve a gradation within the specification limits, it was done so many trial and errors. It is desirable to initially plot the sieve analysis for all aggregate to be used. The aggregates gradation curve used for this study is found to be satisfying the ERA standard technical specification (2002, 6400/8).

3.2 CLEANING, SHREDDING, MELTING AND PULVERIZING OF WASTE PLASTIC BOTTLES

Waste plastic bottles were collected from surrounding environments such as solid waste disposal sites, streets, market areas, hotels, roads, garbage trucks, temporary solid waste storage tanker and from public and non-public meeting halls and so on. It is abundantly accessible everywhere since we use it in our day to day activity. The collected plastic bottles were washed because they should be free from dust and were cut to small parts less than or equal to 9mm using scissors. Then small pieces of plastic were melted at 180ºc for 30 minutes in the oven. Then the melted plastic was cooled down and became solid which was finally pulverized using a hammer. The pulverized waste plastic bottle was used in different percentages for the laboratory experiments 0%, 4%, 6%, 8% and10% by weight of aggregate particles.

3.3 PREPARATION OF PLASTOAGGREGATE

Plastoaggregate means that the plastic coated aggregate. The pulverized plastic was weighed and added over the aggregate in powder form less than or equal to 2.36mm and thoroughly mixed to form a uniform distribution of plastic over the whole aggregate and then heated at 160ºc for two hours. This gives a uniform distribution of plastic over aggregates as plastic gets soften and form a coat around aggregate. The resultant coated aggregate was mixed with hot bitumen of 60/70 grade bitumen which was also heated at 160ºc.

3.4 PLASTOAGGREGATE BITUMEN MIX

Both Plastoaggregate and bitumen at heat state were mixed at 170ºc by automatic mixing machine which was adjusted for two minutes. The plastoaggregate remains in the softening state and bitumen was also at heat state was added which mean that both plastic and the bitumen are in a liquid state which enables easy diffusion. This increases the surface area of contact which helps the interaction process. As soon as bitumen is added to plastic coated aggregate a quantity of bitumen diffuses through plastic layer causing its bonding with aggregate. The aggregate is already bonded with plastic. This results in a strong bond between polymers of plastic, aggregate and bitumen, which was very difficult to break as we see the marshal test result and volumetric properties.

3.5 OPTIMUM BITUMEN CONTENT

To determine optimum binder content, in this study there were marshal specimens for bitumen content of various percentages from 4-6% by 0.5 increments was established without plastic (conventional method). After the marshal test (stability and flow value) were recorded and volumetric properties (VMA, VFA, VA, bulk density) was computed and evaluated. Lastly, the optimum bitumen content was obtained as 5.33% by weight of the total mix. This was obtained at an average of the percentage of bitumen at the highest stability, high bulk density and air voids of 3-5%.

3.6 MIXING PROCEDURE FOR PLASTIC MODIFIED BITUMEN CONCRETE MIXES AND MARSHAL TESTS

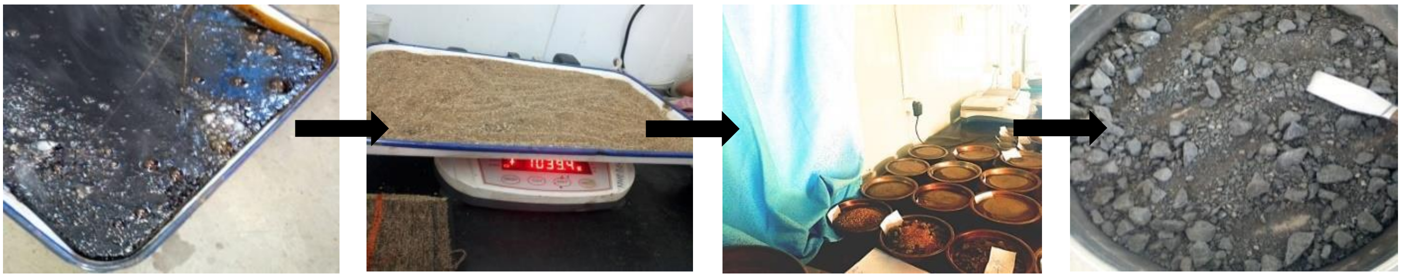


Fig. 1(a) **Fig. 1(b)** **Fig. 1(c)** **Fig. 1(d)**

Fig. 1: Melting, Pulverizing, Adding and Mixing of Plastic Respectively

(a) Plastic waste bottles were cleaned and cut into a size between less than or equal to 9mm using scissor. Then it was melted in the oven at 180°C for 30 minutes and after cooling it becomes solid. Then the solid plastic was pulverized into small plastic aggregates > 2.36mm. Finally, the required percentage of pulverized plastic and aggregate was weighed and mixed to form a uniform plastic aggregate mixture.

(b) The plastic and aggregate mixture was taken by iron pan heated together at 160°C for two hours. During this time the plastic became liquid and becomes a good binder to the aggregate. It gave an oily coat to the aggregate. Since the filler became burnt if it was heated for a long time with the coarse aggregate; the filler was heated by separate pan for up to 30minutes. Simultaneously the 60/70 bitumen was heated at 160^{0}c, and then both the plastoaggregate mixture at heat state and the bitumen at heat state were transferred to the mixing chamber. This is done so as to obtain a good binding and to prevent weak bonding. During this process, the temperature is under control by using pocket thermometer which was mostly ranges between 140-150°C.

(c) The plastoaggregate mixture and bitumen both at heat state were mixed in asphalt mixer adjusted at a temperature of 170°C for 120 seconds (2 minutes).

(d) lastly, the heated aggregate and bitumen was filled in casting mold which was heated in the oven up to 160°C and the casting mold was taken to marshal compaction machine which was adjusted to 75 numbers of blows were done on each side of the sample and the compaction temperature was up 140-150°C then each sample was marked with white chalk and kept separately.

(e) Each sample was marked and kept separately for each percentage of plastic (0%, 4%, 6%, 8%, and 10%) by weight of aggregate and for each percentage of plastic, three samples were prepared. Hence the average test values of three samples were taken. After demolding the specimen and putting it into the water bath adjusted to a temperature of 60^{0}c for 30 minutes; the marshal test was done to determine both marshal stability and flow value. The thickness should be 63.5mm otherwise correction factor should be applied. After determining the weight of the specimen in air, SSD and in water, the volumes of the samples were determined. The volume of the sample is calculated as the weight of the sample in SSD minus weight of the sample in water. Bulk density (bulk specific gravity) of a sample is the ratio of the weight of a sample in the air to the corresponding volume of the sample. Bulk specific gravity, maximum theoretical density, bitumen volume and different volumetric properties such as VA, VMA, VFA, were determined to decide the optimum plastic content which was finally decided as 5.33%.

3.7 OPTIMUM PLASTIC CONTENT

Marshall Specimen with various percentage of waste plastic content by weight of aggregate was formed and marshal tested was done. Three samples were prepared for each per cent of plastic and the average test result was taken. According to marshal test results and volumetric properties, the average plastic content at maximum stability, maximum bulk density and 3-5% air voids were considered as optimum waste plastic content which was finally selected as 4%. The maximum stability was obtained at 4% plastic which was 20.66 KN, maximum bulk density of (2.59gm/cm3) was obtained at 0% plastic because plastic bottle has less specific gravity than aggregate, and 3.25% air voids were obtained at 8 % plastic which was tolerable and within in ranges of specification limit. The optimum plastic content was selected at the average of (4%+0%+8%) = 4 % of the plastic bottle.

4. RESULT AND DISCUSSION

In this chapter, the analysis of all laboratory results and discussions were included. The analyses were categorized into two divisions. The first one was analyzing marshal test result and volumetric properties of conventional (plain) BC mix to determine the optimum bitumen content (OBC). The second one was investigating the effects of replacing the aggregate with a waste plastic bottle (PET/PETE) in modified BC mix was experimented and analyzed to determine the optimum plastic content (OPC).

In Hot Mix Asphalt, binder and aggregate are blended together in precise proportions. The relative proportions of these materials determine the physical properties of the HMA and ultimately how the HMA performs as a finished pavement.

In this investigation the Marshall tests such as stability, flow value were measured and volumetric properties such as bulk density, voids in mineral aggregate, voids filled with asphalt and air voids were computed to obtain optimum bitumen content on conventional asphalt mixture which was 5.33% after laboratory results. In a similar manner, it was done for modified asphalt concrete mixture to determine the optimum plastic content (OPC) which was finally selected as 4% by weight of aggregate.

4.1 AGGREGATE GRADATION CURVE FOR THE MIX DESIGN

Asphalt mix requires the combination of fine and coarse aggregates, having different gradations, to produce an aggregate blend that meets the gradation specifications for a particular asphalt mix. All AASHTO sieve size were used, those are 25mm, 19mm, 13.2mm, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm and filler. Table 4.1 below shows that the final proportion of each aggregate material in asphalt binder surfacing. The proposed aggregates gradation curve is found to be satisfying ERA standard technical specification (2002, 6400/8). All aggregate pass through the first sieve size two sieve sizes which mean that 100% pass and zero per cent retained. After so many trial and errors, the blend proportion of 36%, 8%, 14%, 37% and 5% were used for a combined aggregate of 10-20mm, 5-10mm, 3-5mm, 0-3mm and filler respectively. Then after combined aggregate were computed by using the blend proportion determined and it fell within the range of specification.

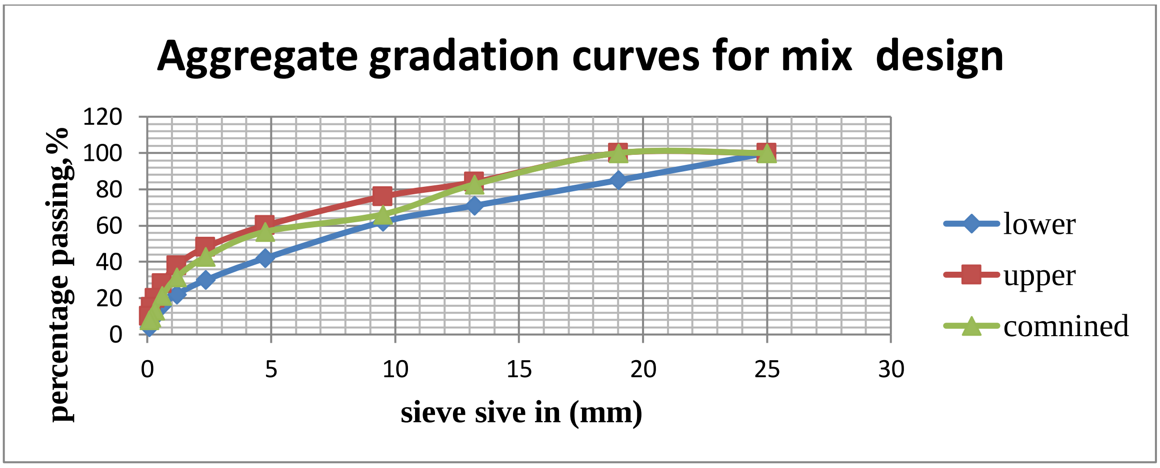


Fig. 1: Aggregate gradation curve for the mix design

4.2 MARSHAL TEST RESULTS AND VOLUMETRIC PROPERTIES MODIFIED BC MIXES

As shown in Table 4.3 below, various percentages of plastic content (0%, 4%, 6%, 8% and 10%) by weight of aggregate was used to partially replace aggregates and the marshal test results of conventional asphalt mixtures mean that zero percentages of plastics compared with plastic modified one. Hot mix asphalt (HMA) with pulverized plastics bottles, when replacing 10% of aggregates, by plastic bottle reduced the mix density from 2.51 to 2.28, increased flow values from 2.93mm to 4.10mm, decreased the VFA from 98.06 to 49.46 and when 8% of aggregates was replaced by plastic bottle, increased the VMA from 12.39 to 22.32 when compared to the results of conventional mix. The marshal stability decreases as the percentages of plastic increases but maximum stability was obtained at 4% plastic (20.66KN) which was greater than the marshal stability of conventional one 20.03KN. The stability of BC mixture modified with PET decreased with increase in polyethylene content, but it attains a maximum at 4% modifier content. The best thing is that the marshal stability results at any percentage replacement fulfils the standards of the specifications which requires > 9KN. This tells that bitumen concrete mix with partial replacement of aggregate by plastic has a maximum load-carrying capacity at the standard test temperature of 60^0c.

The flow value of modified BC mixtures increased with increase in PET proportion by weight of aggregate in BC mixtures. Almost all percentage replacement fulfils the specification standards which require the flow value of 2mm-4mm. This implies that as the percentage of plastic increases, the resistance to deformations under heavy wheel loads increases. The percentage of air voids in BC mixtures decreased with increase in PET bottles but the optimum air voids tolerable according to the standard, which requires percentage air voids of (3-5%) was attained at 8% of PET bottles by weight of aggregate which was as 3.25%. As a conclusion, the percentage of air voids of the unmodified mixture was better than the PET modified bitumen because the plastic fills the void space even if still the air voids was tolerable. This has its own advantage in order to reduce water absorption. The PET modified BC mixture with partial replacement of aggregate by PET gave the lowest bulk density than the conventional BC mixture. This has also its own advantage in order to reduce the hauling cost. The voids filled with mineral aggregate (VMA) increased with an increase in the proportion of PET bottles. Again surprisingly almost all percentage replacement of aggregate by plastic bottle attained the requirements of the specification of VMA value >13%. The voids filled with asphalt decreased with an increase in the proportion of PET bottles as partial replacement of aggregates but 4% replacement of aggregate by plastic attained fails within specification ranges of 65-75%.

Table 1: Marshal Test Results and Volumetric Properties Plastic Bottle Modified BC Mixes

% plastic	Stability(KN)	flow v.(mm)	VMA	VFA	VA	Bulk d
0	20.03	2.93	12.39	98.06	3.12	2.51
4	20.66	3.59	17.70	66.24	2.16	2.42
6	19.34	3.31	19.51	58.80	2.21	2.37
8	19.90	3.83	22.76	49.54	3.25	2.32
10	18.58	4.10	22.32	49.46	2.37	2.28

4.3 PERCENTAGE OF PLASTIC VS. STABILITY

The Marshall Stability‟ of the bituminous mix is defined as maximum load carried (kg) at the standard test temperature of 60^0c. Marshal stability (MS) value increases by using polymer-coated aggregate; however, at higher plastic contents it decreases [5]. The asphalt mixture containing 4% recycled plastic and 1% recycled glass exhibit higher values of Marshall stability compared to the control sample, indicating that these asphalt mixtures have high load-withstanding strength [8]. It is observed that Marshall Stability value increases with polyethylene content up to 4% and thereafter decreases (Vootukuri & B., 2018).

Reinforcing the previous study, maximum marshal stability value was obtained at 4% plastic, but as the whole the stability decrease as the proportion of aggregate increases which was shown in Figure 3.

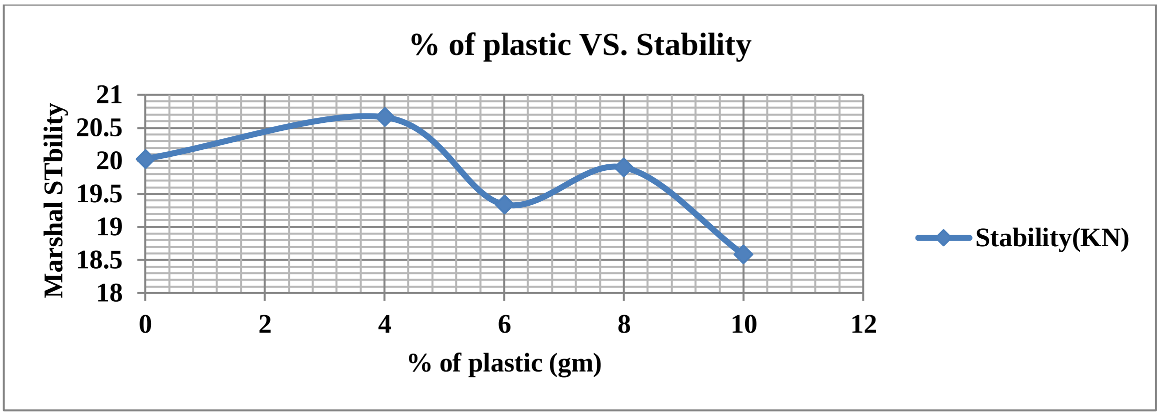


Fig. 2: Percentage of plastic vs. stability

As depicted in Figure 4 below, the trend line decreases from upside down from left to right and negative slope which mean that the two variables (percentage of plastic and stability) have a strong inverse relationship and according to the trend line for casted the value of stability still decreases as the percentages of plastic of increases. The r-squared value implies that there is a somewhat strong linear relationship between stability values and percentage of plastic.

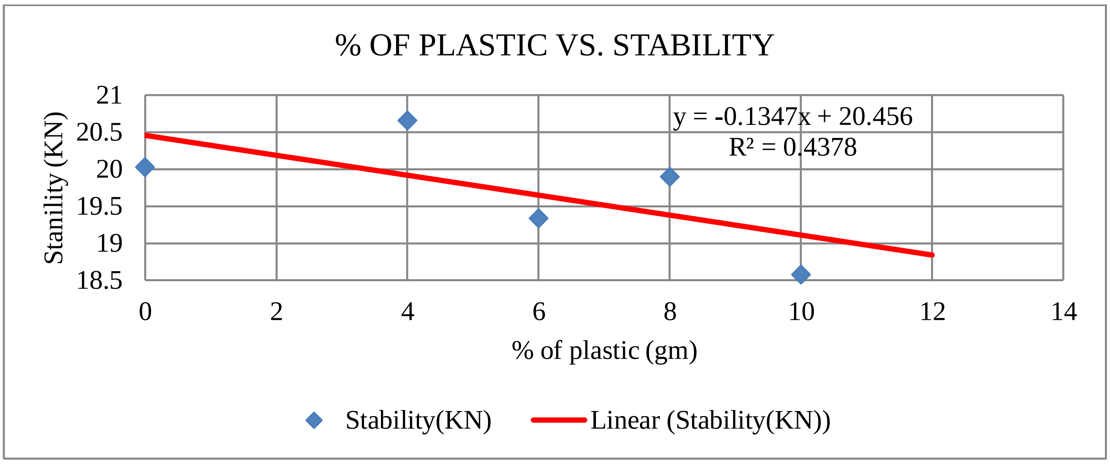


Fig. 3: Linear Regression Models for Stability and Percentage of Plastic

4.4 PERCENTAGE OF PLASTIC VS. FLOW VALUES

Flow is the total amount of deformation which occurs at maximum load.

The Marshall Flow value decreases upon addition of polythene i.e. the resistance to deformations under heavy wheel loads increases (Vootukuri & B., 2018). With the addition of plastic waste, flow values are less than that of conventional values (Jadon, 2016). Flow value of bituminous mixes is found to be increasing in each series with an increase in percentage replacement by waste additives (Bansal et al., 2017). From Figure 5 depicted below, in contradiction to the above conclusion of (Vootukuri & B., 2018) and confirming (Bansal et al., 2017), marshal flow values increase continuously with the addition of plastic. And almost all the values falls under the specifications range 2mm-4mm.

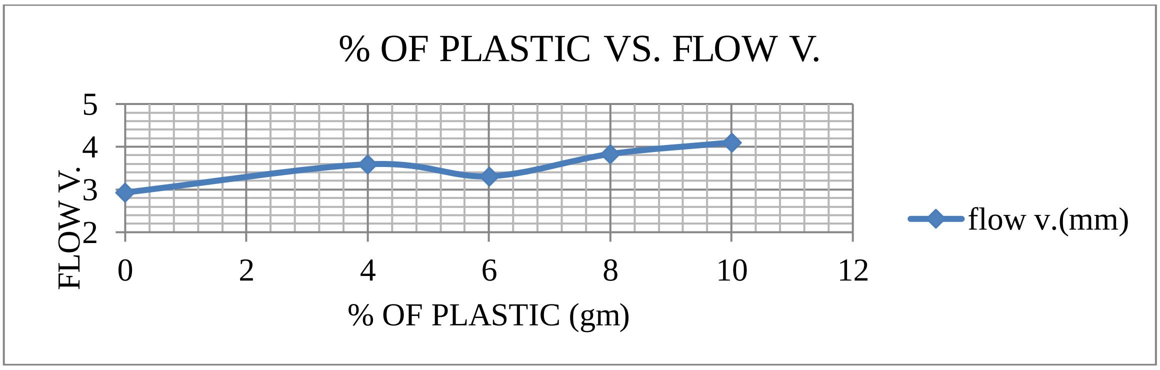


Fig. 4: Percentage of Plastic vs. Flow Value

As portrayed in Figure 6 below, the marshal flow value and percentages of plastic have a direct relationship which means that as the percentages of plastic increases the marshal flow values also increases. Since the trend line is up from left to right indicate that there is a positive slope (direct relationship) between flow value and percentage of plastic. According to the trend line forecasted the value of flow values for the future increase of percentages of plastic it still increases. As the r-squared value is nearest to one, imply that there is a strong linear correlation between flow value and percentage of plastic. Since the data points lay down near the trend line.

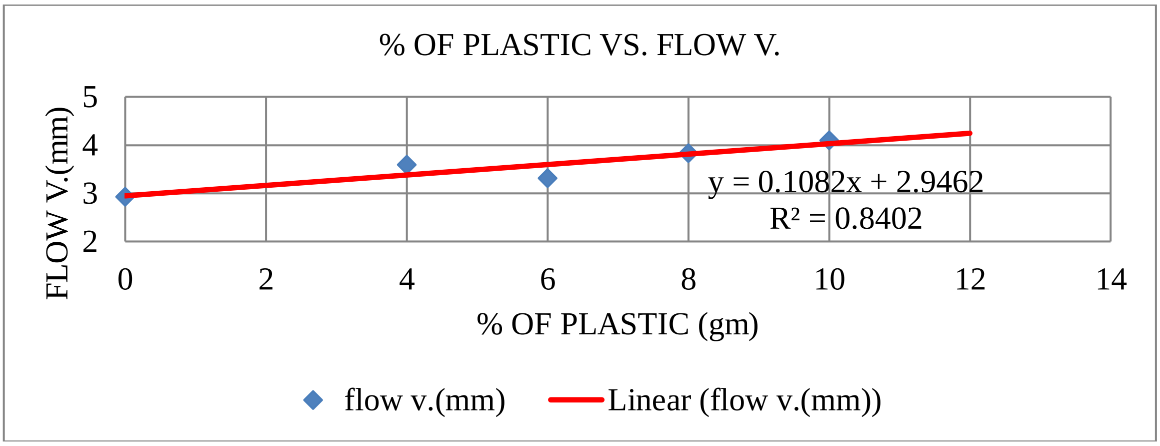


Fig. 5: Linear Regression Models for Flow Value and Percentage of Plastic

4.5 PERCENTAGE OF PLASTIC VS. VOIDS FILLED WITH MINERAL AGGREGATES (VMA)

It is the volume of inter-granular void space between the uncoated aggregate particles of a compacted paving mixture that includes the air voids and effective bitumen content. VMA is expressed as the percentage of the total volume of the compacted paving mixture. It is the void spaces that exist between the aggregate particles in the compacted paving HMA, including the space filled with the binder. VMA represents the space that is available to accommodate the effective volume of binder (i.e., all of the binder except the portion lost by absorption into the aggregate) and the volume of air voids necessary in the HMA. The more VMA in the dry aggregate, the more space is available for the binder. With the addition of plastic, VMA values are increased to that of a conventional mix (Jadon, 2016). Depending on Figure 7 below, confirming the previous study (Jadon, 2016), the value of VMA increases as the percentages of plastic increases but the further increment of the amount of plastic decreases the value of VMA.

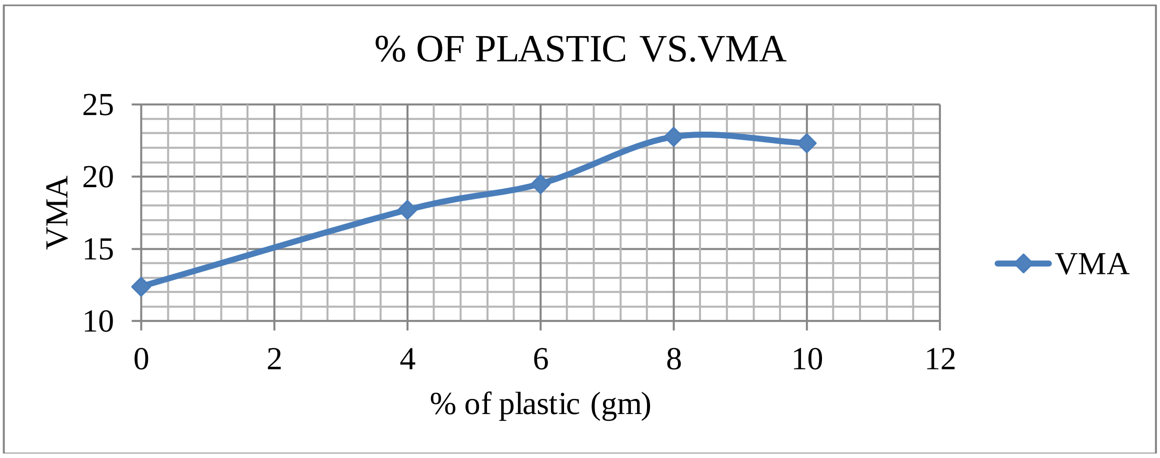


Fig. 6: Percentage of plastic VS. VMA

As shown in Figure 8 below, since the trend line is up from left to the right (the positive slope) imply that there is a direct relationship between the variables (percentages of plastics and VMA) which mean that as variable increases the other increases and the reverse is true. R–squared value (0.9451) which is nearest to one implies that there is a strong linear correlation between voids in mineral aggregate and percentages of plastic.

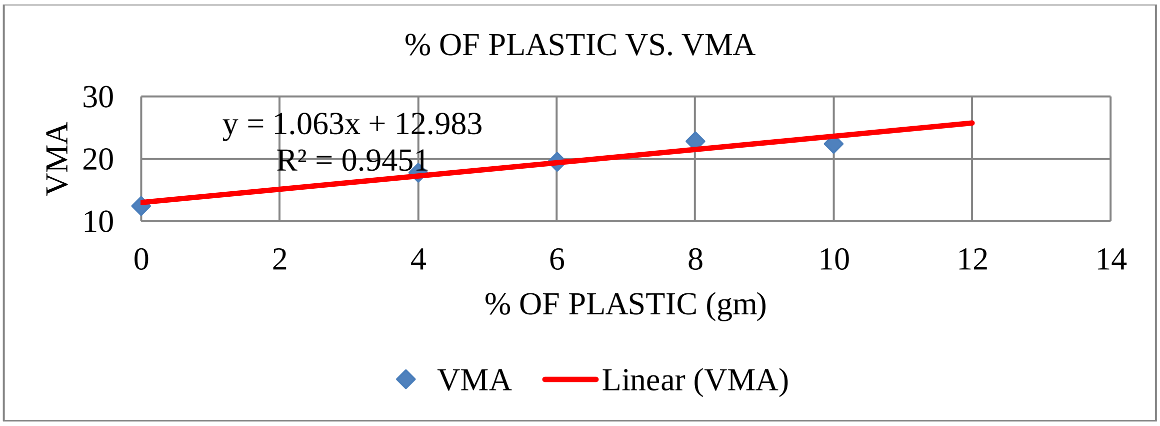


Fig. 7: Linear Regression Models for VMA and Percentage of Plastic

4.6 PERCENTAGE OF PLASTIC VS. AIR VOIDS (VA)

In MS-2 VA is the total volume of small pockets of air between coated aggregate particles throughout a compacted paving mixture, expressed as the percentage of the total volume of the compacted paving mixture. A certain percentage of air voids (3-5%) is necessary for all dense-graded mixes to prevent the pavement from flushing, shoving, and rutting. It can be increased or decreased by lowering or raising the binder content or controlling the amount of material passing the No. 200 sieve such as baghouse dust in the HMA. Air voids may be changed by varying the aggregate gradation in the HMA. Air voids are decreasing but the value decreases with an increase in plastic waste content (Jadon, 2016). According to Figure 4.8 below, the percentage of air voids decreases as the percentage of plastic increases but for further increment in plastic air voids also increases and attains optimum air voids at 8% of plastic, which was 3.25% and fulfils the requirements of specification standard of 3%-5% air voids.

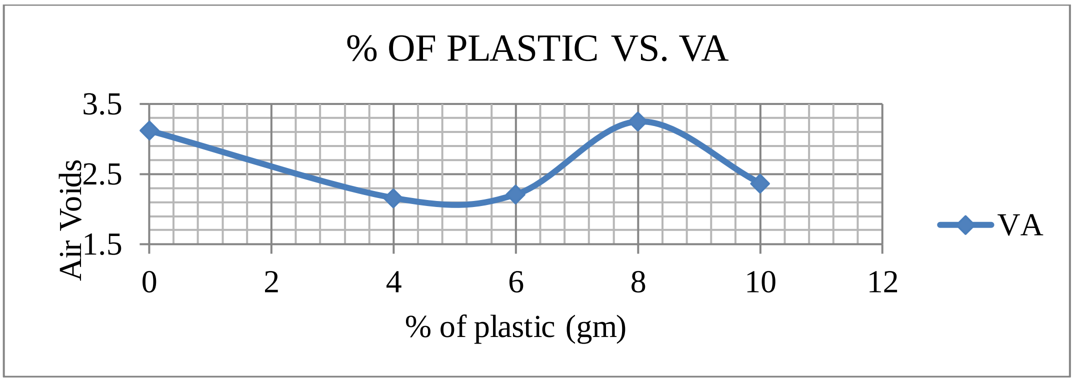


Fig. 8: Percentage of Plastic vs. Air Voids

As rendered in Figure 10 below, the trend line in linear regression model is down from left to the right (the negative slope) to little extent imply that there is inverse relationship between the variables (percentages of plastics and VA) which mean that as one variable increases the other decreases and the reverse is true. R–squared value is near to zero (0.0512) implies that there is no linear correlation between the percentage of air voids and percentages of plastic.

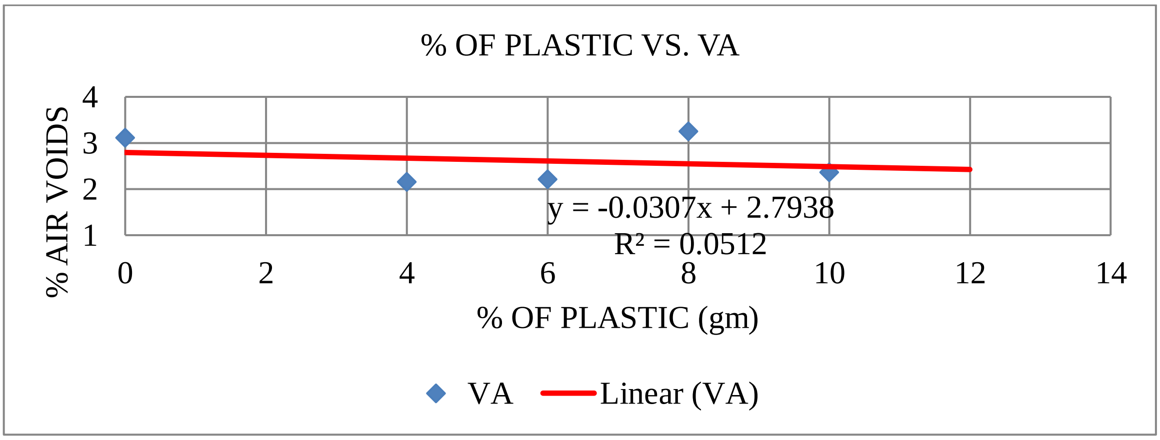


Fig. 9: Linear Regression Models for Air Voids and Percentage of Plastic

4.7 PERCENTAGE OF PLASTIC VS. VOIDS FILLED WITH ASPHALT (VFA)

In MS-2 VFA are defined as the void spaces that exist between the aggregate particles in the compacted paving HMA that are filled with a binder. VFA is expressed as a percentage of the VMA that contains binder i.e., is the percentage of VMA that is occupied by the effective bitumen. As the proportion of plastic increase the VFA value increase as compared to that of the conventional mix (Jadon, 2016). According to Figure 4.10 below, contradicting to the previous study, the value of VFA decreases as the percentages of plastic increases and the reverse is true. i.e., the two variables (Percentage of plastic and voids filled with asphalt) inversely proportional. The VFA value of (66.24) at the 4 per cent of plastic falls inside the standard specification ranges which are 65-75%.

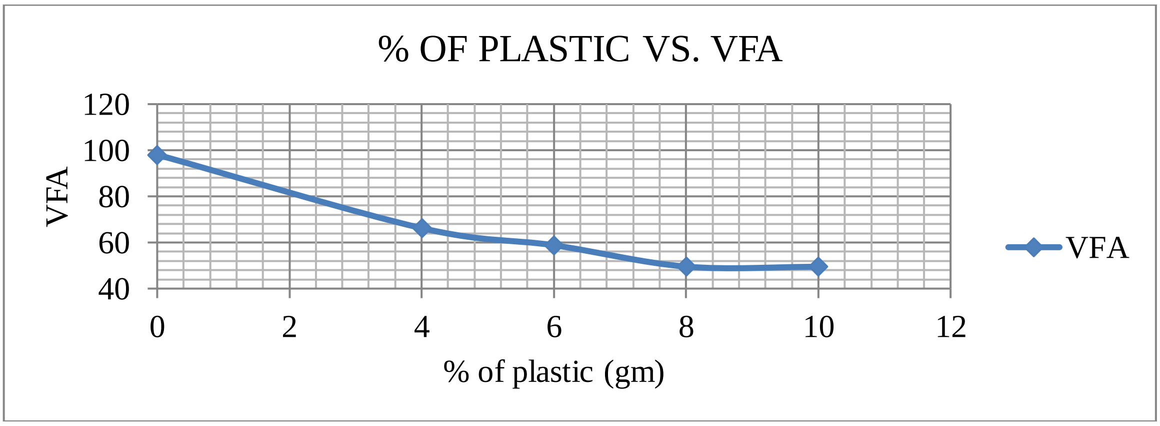


Fig. 10: Percentage of Plastic vs. VFA

As portrayed in Figure 12 below, the trend line of linear regression model is down from left to the right (the negative slope) which implies that there is an inverse relationship between the variables (percentages of plastics and voids filled with asphalt) which mean that as one variable increases the other decreases and the reverse is true. R–squared value is almost equal to one (0.9126) implies that there is a strong linear correlation between the percentage of voids filled with asphalt and percentages of plastic.

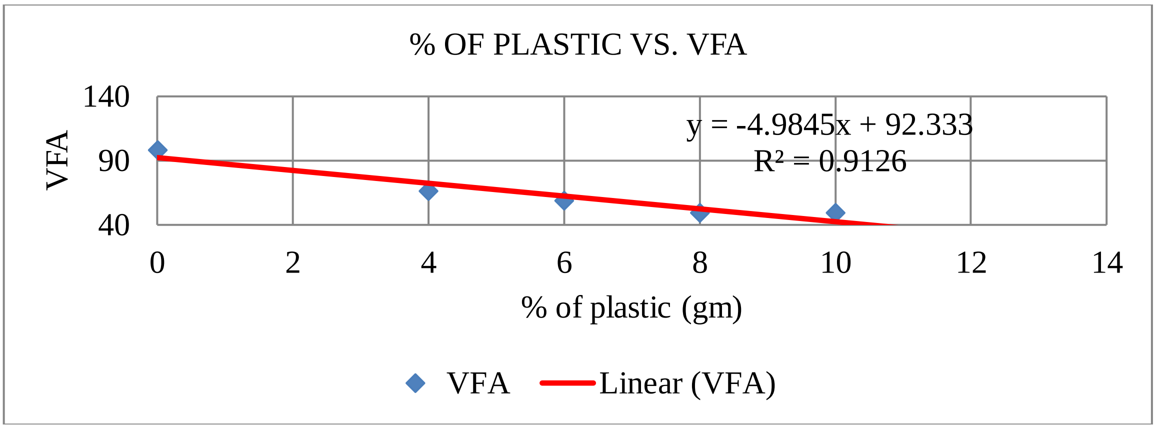


Fig. 11: Linear Regression Models for VFA and Percentage of Plastic

4.8 PERCENTAGE OF PLASTIC VS. BULK DENSITY

It is the ratio of weight in air of the specimen to the difference in weight of the specimen in air and water. The density of the compacted mix is the unit weight of the mixture (the weight of a specific volume of HMA). Density is important because proper density in the finished product is essential for lasting pavement performance. Mix properties are required to be measured in volumetric terms as well as weight. Density allows us to convert from units of weight to volume. In mix design testing and analysis, the density of the compacted specimen is usually expressed in pounds per cubic foot (lb/ft3).

The values of bulk density are decreasing with an increase in waste plastic content (Jadon, 2016). DBM with recycled plastics, mainly low-density polyethylene (LDPE) replacing 30% of 2.36–5mm aggregates, reduced the mix density by 16% (Huang et al., 2007).

As depicted in Figure 13 below, the values of bulk density decrease as the percentages of plastic content increases. This indicated that the two factors are inversely related. The reduction of bulk density has the advantage of reducing hauling cost.

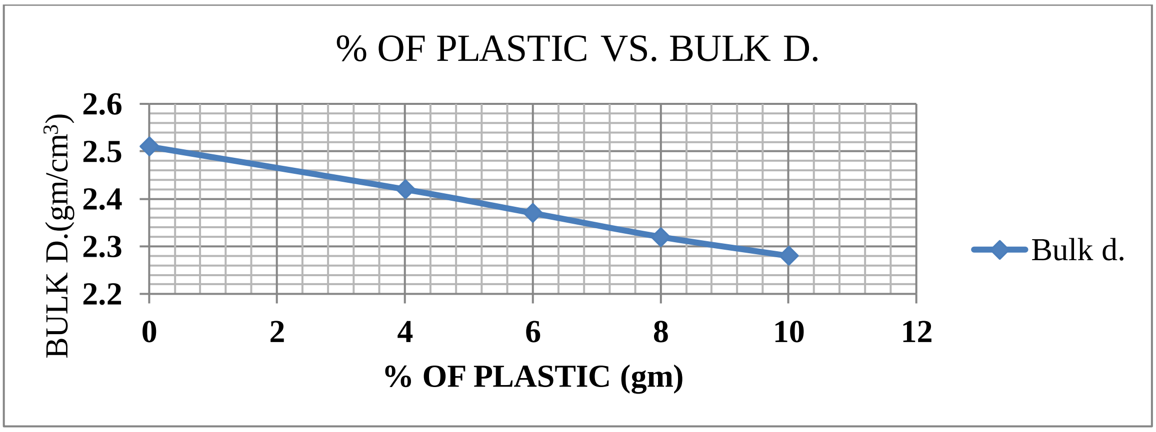


Fig.12: Percentage of Plastic vs. Bulk density

As portrayed in Figure 14 below, the trend line of linear regression model is down from left to the right (the negative slope) which implies that there is an inverse relationship between the two variables (percentages of plastics and bulk density) which mean that as one variable increases the other decreases and the reverse is true. R–squared value is almost equal to one (0.999) implies that there is a strong linear correlation between the percentage of bulk density and percentages of plastic.

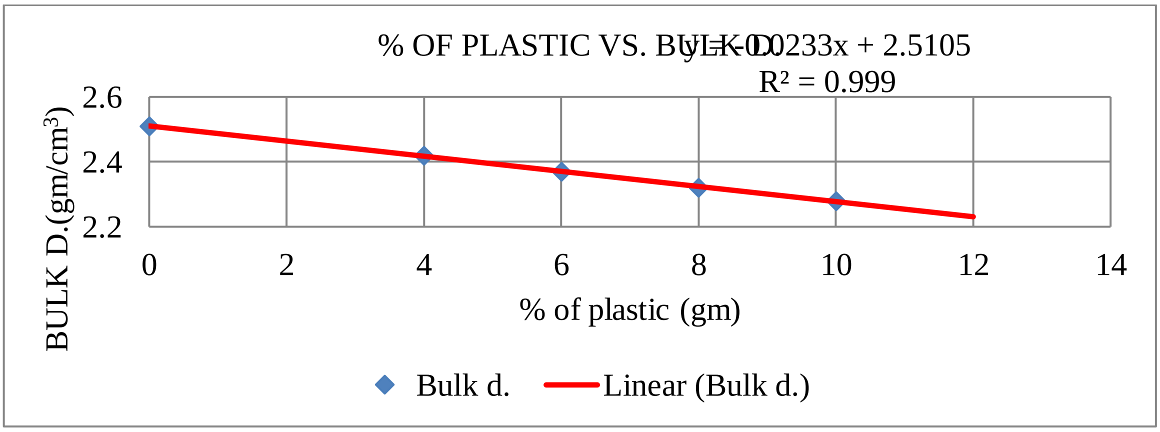


Fig. 13: Linear Regression Models for Bulk Density and Percentage of Plastic

5. CONCLUSION

As the laboratory results of marshal test indicate, application of waste plastic bottles in road construction especially in flexible pavement construction increases the performance of pavement since the overall performance of plastic modifies bitumen concrete mix are better than that of conventional one. And this reduces the aggravating negative impact of a plastic bottle (PET/ PETE) on the environment since the incineration and landfilling does not solve the problem because the plastic bottles can stay up to 500 years to decompose. According to the marshal test results and volumetric properties on conventional bitumen concrete mix, the optimum bitumen content was determined as 5.33% by weight of the total mix.

Then after the specimen was prepared to the modified BC mix with partial replacement of aggregate with a waste plastic bottle by (0%, 4%, 6%, 8% and 10%) by weight of aggregate. The performance of BC mix according to marshal flow value and percentages of plastic have a direct relationship which means that as the percentages of plastic increase the marshal flow values also increases and there is a strong linear correlation between flow value and percentage of plastic. And there is no constant increment or decrement of marshal stability values, but the marshal stability values fluctuate as the percentage of plastic increase. But there is maximum stability of (20.66KN) at the 4% of a waste plastic bottle (PET/PET) was added as an aggregate which was higher than that of 0% plastic (conventional BC mixes) which was recorded as 20.00KN. As a percentage of plastic increases the bulk density decreases; this has the advantage to reduce the hauling cost and there is a strong linear correlation between the two. As the percentage of plastic increases, the VFA decreases and there is a strong linear correlation between the two. There is a direct relationship between percentages of plastics and VMA but the further increment of the amount of plastic decreases the value of VMA and there is a strong linear correlation between voids in mineral aggregate and percentages of plastic. And there is no constant increment or decrement of the percentage of air voids with an increment of plastic, but the percentage of air voids fluctuate as the percentage of plastic increase. But to a little extent imply that there is an inverse relationship between percentages of plastics and VA. There is no linear correlation between the percentage of air voids and percentages of plastic since the r-squared value is near to zero.

According to the comparison of laboratory test result and the standard specification of AASHTO, the marshal stability value should be greater than or equal to 9KN, marshal flow value should be within ranges of 2-4mm, voids filled with mineral aggregate should be greater than or equal to 13%, voids filled with bitumen should be within 65-75%, the optimum percentage of air voids should be 3-5% and all the test results at each percentage replacement of aggregate by plastic content fulfils the standard specification requirement of stability, flow value and voids filled with mineral aggregate. But only 4% replacement of aggregate by plastic fulfils the requirements of voids filled with mineral aggregate and air voids at 8% of plastic content was tolerable.

5.1 RECOMMENDATIONS

Depending on the laboratory results and the current situation of solid waste disposal problem especially plastic bottles; this study had great findings and becomes great congratulations for developing countries like Ethiopia which have poor solid waste management systems. This study has double advantages to improve the performance of flexible pavements and to reduce environmental pollution through non-biodegradable PET/PETE plastics. This non-biodegradability property of plastic was a great advantage for the application of plastic in BC mixes since it resists different climatic and harsh weather condition. The researcher recommends other researcher and organizations for the following points.

(a) Waste plastic bottles (PET/PETE) can enhance the performance of BC mixtures if it were used to partially replace aggregate. For this matter this study recommends different governmental (ERA and ACRA) and non-governmental organization involved in road construction works, it is better to include such waste material input as an important improving agent in flexible pavements at the certain percentage as new finding technology on flexible pavement especially with high traffic volume. It is better to apply this new construction technology on the ground and to adopt it.

(b) Further studies are recommended to investigate the cost-benefit analysis of using was plastic bottles as partial replacement of aggregate in BC mixes.

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