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Sustainable Construction Practices in Road Construction

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ABSTRACT. *Sustainable construction has been gaining importance due to the effects of climate change we experience globally. The effects are pronounced day by day. The construction sector is growing globally in a paced manner, particularly in developing countries. The construction sector is the largest consumer of energy, particularly fossil fuels. The prime among the construction sector is pavement construction, providing connectivity to places. Hence it is paramount to practice sustainable principles in road construction. This paper investigates the use of alternate sustainable construction materials in road construction.*

Keywords: Bitumen, Sustainable, Construction, Alternate, Materials, Road, Pavement

1. INTRODUCTION

The main objective in sustainable construction is to minimise the use of energy consumed in construction, minimising the use of energy-intensive materials needed for construction and the use of alternate materials, which consume less energy, in place of traditional construction materials.

United Nations Convention on Climate Change (UNCCC), Paris 2015 has set a goal to limit the increase in global average temperature to 1.5 degrees Celsius over the pre-industrial levels, by the year 2030[1]. We are witnessing a rise in the global average temperature and its consequent effects such as a rise in sea levels, droughts and desertification, excessive rains and flooding, changes in the global weather pattern, and the consequent challenges to the lives of the habitats on earth.

The construction sector has been the largest consumer of global energy (36%) and is also responsible for about 39 % of global emissions related to CO2 and the other greenhouses [1]. A pavement consumes around 100 to 300 Mega Joules (MJ) of energy for each square meter of its construction, depending upon the thickness of the overlay, aggregate haul distance, and other variables [2]. As an example of energy consumed during the pavement construction, assuming a lane width of 3.6 meters (12 feet), this translates to a range of 0.4-1.2 Terajoules of energy per lane-kilometer of pavement construction [2].

As seen from the above, the road construction sector is one of the energy intensive construction sectors and the practice of sustainable construction is important to ensure environmentally sustainable connectivity amenable to lives on earth.

2. PRESENT PRACTICES IN ROAD CONSTRUCTION

A road is generally constructed either as rigid pavement or as flexible pavement depending upon the requirement. However flexible pavement dominates the world of road construction for their ease in construction, maintenance, and economics.

The materials for flexible pavement generally include the Bitumen (Asphalt), the binder, and the aggregates. Bitumen is the by-product of crude oil distillation at the petroleum refineries. The production of asphalt binder mainly releases three different types of Green House Gases (GHG) per tonne of its production, namely, CO_2 at 174.244 kg/t, Nitrogen Oxide (NOX) at 0.770 kg/t, and Methane (CH_4) at 0.595 kg/t emissions for straight-run asphalt binder production [3]. The production also involves an energy consumption of 510 MJ/t during the production of Bitumen [3].

The production of aggregates includes the blasting of parent rock materials, quarrying, transport, crushing, and screening the product. These processes involve substantial energy and release the CO_2, CH_4, NOX, and Sulphur hexafluoride (SF_6).

The production of bituminous mixtures at the designated Central Mixing Plant (CMP) involves transportation, storage of bitumen and aggregates, collection of bitumen and aggregates at the CMP plant for the preparation of mix, heating of aggregates and bitumen at the prescribed temperature, mixing of bitumen and aggregates and the discharge of bituminous mixture in the transport vehicles. The use of bituminous mix again involves energy during transportation, laying at the site, and in the rolling stage.

For a 20 KM long bituminous pavement construction with an 18 cm deep bituminous layer, for a road width of 28m, it can be seen that 97.19% of the total GHG emissions are due to the mixture mixing phase and raw materials production phase, wherein 54.01% are from the mixture mixing phase, and 43.18% are from the raw materials production phase. About 1.35% of the total GHG emissions are due to the raw material and mixture transportation phase. Only 0.86% and 0.61% of the total GHG emissions are due to the laying phase and compacting phase [3].

Hence it can be inferred from the above that raw materials for bituminous mix and their production should be considered from the perspective of sustainable construction. Even though the material phase is a key contributor to sustainable development, sustainable construction could also be thought of from the viewpoint of planning, design, construction, maintenance of bituminous pavement.

But sustainable construction of roads from the perspective of construction materials is discussed here.

3. ALTERNATE CONSTRUCTION PRACTICES

At present widespread research is going on around the world, to identify an alternate binder to bitumen in the construction of pavements or to substitute the bitumen partly with suitable materials having binder qualities as that of bitumen. Promising alternatives to the bitumen are outlined as follows.

3.1 Use of Plastics

Plastics though revolutionised the world of packaging and has been in the forefront for its use as a leading material used by mankind. However, mankind has not realised the effects of the use of plastics, as their disposal and their environmental effects became a challenge for them. Even though a substantial amount of plastics are recycled today, governments around the world have been advocating the use of alternate materials. Therefore the use of plastics as a partial substitute in the production of the bituminous mix is gaining importance.

Use of plastic, obtained from waste plastics such as plastic bags, plastic bottles, plastic cups, plastic straws, etc., are being practiced worldwide in the road infrastructure industry to achieve the dual purpose of effective disposal of waste plastics and to enhance the physical properties of bitumen as a partial substitute to the bituminous binder. Plastics are made from synthetic polymers containing Polyethylene (PE), Polyvinyl chloride (PVC),Polypropylene(PP), and Ethyl vinyl acetate(EVA).But plastics made from PE such as High Density Poly Ethylene(HDPE ♴), Low Density Poly Ethylene(LDPE ♶), and Poly Propylene(PP ♷) are known to make a substantial contribution as a partial additive for Bitumen, as their melting temperature falls below the mixing temperature of the bituminous mix[4]. Thus various research findings recommend the addition of recycled plastic either separately or in a combination at a rate of 5 % to 10 % of the weight of bitumen and the optimum being at 8 % [5]. Hundred percent plastic roads are being laid, at certain metropolitan cities, using recycled plastic blocks in urban footpaths, parking areas and in roads carrying light traffic.

3.2 Recycled Bituminous Pavements (RBP)

Recycled bituminous pavement technology is gaining importance because tonnes of bitumen are buried underneath, as overlays are laid over the existing bituminous pavements. The bitumen is 100 % recyclable [6]. Except for a few oil-producing nations in the world and those in the Organization of Petroleum Exporting Countries (OPEC), other countries oil needs are met mostly through imports, which necessitate them to spend huge foreign exchange for the import of crude oil. Further, the CO2 and other gases released during production and the use of bitumen in the preparation of bituminous mix is largely avoided when the recycled bitumen is used. Thus making this technology green, therefore this technology is cost-effective and sustainable. RBP can be manufactured either by using cold mix technology or by hot mix technology and can be manufactured either at the site as in-place pavement or in a central hot mix plant [7].

3.3 Use of Ground Tyre Rubbers

Ground Tyre Rubber (GTR) of around one billion reach their useful life in a year and around 4 billion GTR's are currently in landfills and stockpiles worldwide [8]. Hence the disposal of the ground tyre has become a major challenge to the governments as they pose a severe challenge to the environment.

An effective solution to recycling the GTR's has been found in the use of shredded GTR's in the construction of pavements as a partial substitute. GTR's are made of a group of polymers called elastomers. GTR's are shredded and crumbed to the required size and then blended with bitumen at a specified temperature. Studies show that that the cracking and rutting resistance of bituminous mix are greatly improved and they enhance the durability, reduce aging, and oxidation of the mix [9]. The crumbed GTR's also show the improved resistance to skid, in addition to the above characteristics.

3.4 Use of Lignin as partial Substitute

Lignin is one of the most abundant natural polymers which originates from nature and is present in vascular plans. The chemical structure of the lignin reflects the structure for bitumen and therefore it could be used as an alternative for bitumen. One of the most predominant sources of lignin is the paper industry. In the process of papermaking, tremendous efforts are made to remove as much lignin as possible. The residue is a side stream called "black liquor" in which lignin is present. The outcomes of various research conducted on the use of lignin have shown that lignin can replace bitumen by around 10 to 25 % and the results are encouraging. The addition of lignin results in visco-elastic behaviour of the mix and increasing content of the lignin results in changes in the stiffness of the mix. Research is also being carried around the world to replace the bitumen with 100 % lignin [10].

3.5 Bio Bitumen

The use of wooden wastes, coffee wastes, etc., coconut fibres, sisal fibres, cellulose fibres , polyester fibres, starch, waste glass, cigar wastes, household wastes, etc., as modifiers, are seen as potential modifiers for the greening of bitumen technology.

Wooden wastes i.e. wooden chips, saw dust, shavings etc., from sawmill and wood processing industries can be harnessed and the processed wooden material is converted in to bio-oil by means of the pyrolysis process. The pyrolysis process is defined as a process whereby the waste wood chips and shavings were rapidly heated in a vacuum thereby decomposing them into solid bio-char, vapours, and aerosols. Rapid cooling of pyrolysis vapours and aerosols produces bio-oils [11]. The bio-oil is mixed with bitumen for use as bio oil-modified bitumen. The addition of Bio-oil to the bitumen improves fatigue characteristics and rutting of the mix [9].

It is known that about 16 billion pounds of waste coffee grounds are produced worldwide in a year [9], as coffee is consumed throught the world [12] and therefore it appears that there exists large feasibility for using waste coffee as a substitute for asphalt binder. Waste Coffee bean wastes are grounded to a powder form and mixed with asphalt at 4 to 8 % the weight of bitumen. The coffee bean modified bitumen shows delayed characteristics of aging and delays the oxidation of bitumen [13].

The Sisal fibre is obtained from the leaves of the tree "Agave Sisalana" which originated from Mexico and is now cultivated in Brazil, East Africa, Haiti, India, Indonesia, etc., . Sisal fibres are obtained from the outer leaf skin, removing the inner pulp. Sisal fibre is exceptionally durable with low maintenance, minimal wear and tear and it is also recyclable. They are also are anti-static, do not attract or trap dust particles, and do not absorb moisture or water easily. It exhibits good impact absorbing properties [14]. Traditionally, Sisal has been the leading material for agricultural twine (binder twine and baler twine) because of its strength, durability, ability to stretch and resistance to deterioration in saltwater is found to enhance the bituminous properties and is, therefore, is widely used as a partial additive to bitumen [16].

Waste glass from food processing industries and automobile sectors form the chunk of glass waste generated. This waste glass is crushed and added to Hot-mix Asphalt (HMA), to an extent of 5 to 10 % of the mix, and the research in this has proved that the resulting mix improves its mechanical properties [16].

Starch, a natural polymer obtained from trees is blended with paving grade bitumen and the resulting mixture performs well that of some synthetic polymer-based mixtures. The rutting potential and temperature susceptibility of the mix are greatly improved by using starch as a partial substitute for the bitumen mix [16]. Starch is also cheaper than conventional synthetic polymers and is usually extracted from the tropical palm tree stems.

General household waste that includes textiles, paper, and other organic materials is generated plenty in every household. Partial substitute to the bituminous mix is obtained from the incineration of household wastes at around 500◦C in the absence of oxygen, resulting in a black floppy substance having properties of bitumen and this substance is added to the bitumen at a specified temperature [16].

Millions of litres of waste oil are produced by Hotels and Restaurants around the world. This waste oil can be polymerised and the resulting bio asphalt is produced after undergoing the thermo chemical process. Bio asphalt could be added to the conventional bitumen at 10 – 30 % by weight of bitumen. The studies have also shown that addition of this bio asphalt improves the ductile behaviour of the mix, fatigue resistance, and rutting of the bituminous mix [17] .

The use of other materials such as polyester fibres, cellulose fibres, etc., are also being explored, for use as a partial replacement for bitumen by the research institutions.

4.0 ALTERNATE AGGREGATE MATERIALS

Aggregates used in the production of hot mix Asphalt mix are usually hard blue granite aggregates. Manufacture of aggregates involves mining, breaking of rock, pulverisation, screening, deposition, and transportation to the place of the mix. Hence constant depletion of minerals, used in the making of aggregates, is taking place on a huge school making them unsustainable for the future. The manufacturing activities also involve the use of heavy machineries which consumes a lot of fossil fuels, releasing a lot of greenhouse house into the atmosphere. Hence researches have been going on around the globe to find alternatives, which are sustainable for the future. Some of the alternate aggregate materials for the greening of Hot Mix Asphalt (HMA) technology are as follows.

4.1 Blast Furnace Slag Aggregates (BFSA)

Foamed blast furnace aggregates are manufactured from iron slag, which is a by-product in the manufacture of Iron and Iron products. Slag is a non-metallic inert waste product that consists of silicates, alumina silicates, and calcium-alumina silicates, thus it possesses cementitious properties [18].

During the production of Iron, a controlled amount of water is applied to the molten slag to trap the stream in the mass, resulting in a porous and pumice like product. This product is crushed and screened to the required sizes for use as aggregates. The aggregate product is economical, light in weight besides durable [19].

Granulated blast furnace slag aggregates are produced from rapid quenching of blast furnace slag with an excess amount of water during the quenching process, resulting in the sand like property material which could be crushed and screened to the required size, for use as aggregates [19].

4.2. Fly ash aggregates (FAA)

Fly ash aggregates are produced from fly ash, a waste product from the combustion of coal in thermal power plant industries. Thermal power plants continue to hold a substantial share in power production around the world because of the cheaper production of electricity. The production of power in a thermal power plant is always accompanied by the production of fly ash, which is accumulated in tonnes in the power plants, presenting an environmental problem to the locality. Hence their disposal has become imperative to the power plants. Hence the usefulness of fly ash is found in the conversion of fly ash into aggregates and bricks etc,

Fly ash aggregates are produced by mixing fly ash with water and a small number of additives Fly ash aggregate is light in weight and possesses the properties of the aggregates comparable to the natural aggregates. [19].

4.3 Steel furnace slag aggregates (SFSA)

Steel furnace slag aggregates are produced from slag retained after the exothermic refinement of molten iron in the presence of oxygen and fluxes. After air cooling of the slag, the product is crushed and screened to the required size for use as aggregate[19].Steel furnace slag aggregates possess properties similar to the other blast furnace slag aggregates except that they lack some pozzolanic properties. However, they can be well used in the pavement works along with the bitumen [18].

4.4 Demolition waste Aggregates (DWA)

Old Buildings, bridges, culverts, roads, irrigation structures, etc., are replaced around the world on completion of their service life. These old structures are demolished and replaced with new structures. Often the demolished materials are deposited in landfills. However, aggregates from this demolition wastes could be reprocessed and used again wherever possible i.e., they could be used as secondary concrete materials such as in a base course or levelling course and in nonstructural items of a structure and as granular sub-base material in road construction[15].

4.5 Polystyrene aggregates (PA)

Polystyrene aggregates are obtained from crushed plastic wastes and they are used in combination with mineral aggregates to produce lightweight concrete. They can be produced either as polystyrene beads or as granulates of various sizes [19].

5.0 CONCLUSION

Research has been going around the world to produce alternate materials to bitumen and mineral aggregates from various alternatives. Detailed specifications and guidelines should be developed by the construction authorities, based on the research, to enable the use of alternative construction materials.

The alternate materials discussed here may be analysed for their availability, cost of procurement, manufacture, and their use so that they are also economically sustainable, thus making them environmentally sustainable and economically sustainable. However for any specific projects, they may be analysed, to ascertain that the use of sustainable alternatives is socially sustainable.

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REFERENCES

[1]GlobalABC. Regional Roadmap for Buildings and Construction in Asia. 2020-2050. Global Alliance for buildings and construction.

[2] Pavement Interactive studies, 2020, Energy & Road construction – What's is the mileage of roadway?. [cited 30th September 2020]. Available from : https://pavementinteractive.org/pavement - articles/

[3] Ma F M, Sha A, Lin R, Huang, Y, Wang C. Greenhouse Gas Emissions from Asphalt Pavement Construction: A Case Study in China. International Journal of Environment Research and Public Health.2016 13; 351: 1-15.

[4] Brasilerio L, Navarro M B, Martinez R T, Matos J, Rubio- Gamez C D M. Reclaimed polymers as Asphalt binder modifiers for more sustainable roads – A Review. 2019 Sustainability;11:646.

[5] Baskandi D. Bituminous Pavement Recycling–Effective Utilization of Depleting Non-Renewable Resources.The International Journal Of Engineering And Science (IJES*)*, 2017 Volume; 6 (3) : 57-65.

[6] Sasidaran M, Torbahan E, Burrow M.P.N. Using waste plastics in road construction. K4D Helpdesk report.University of Birmingham.2019

[7] Aravind K, Animesh D. Bituminous pavement recycling. Department of Civil Engineering, IIT Kanpur. 2020

[8]WBCSD. Managing end of life of tyres, Full report of World business council for sustainable development.Geneva.2020

[9]Lushinga L, Cao L, Dong Z, Yang C, Assogba C O. Performance evaluation of Crumb rubber Asphalt modified with silicone-based warm additives. Advances in Civil Engineering.2020 Vol; 2020: 1-17.

[10]Vliet D V, Slaghek T, Giezen C, Haaksman I. (2016). Eurasphalt & Eurobitume congress. 1-3; June 2016

[11] You Z, Mills-Beale J, Yang X, Dai Q. Final report on the Alternate materials for sustainable transportation. Michigan Technological University.2012

[12] Blinová L, Sirotiak M, Bartošová A, Soldán M. Utilization of waste from coffee production, Slovak university of technology, Bratislava. 2017 Vol 25; 40.

[13] Zofka A, Yut I. Workshop on alternative binders for Sustainable Asphalt pavement, Transportation Research Board, USA.2012

[14] Debashish K.A laboratory study of bituminous mixes using a natural fibre. Department of Civil Engineering. National Institute of Technology, Rourkela, India. 2012.

[15] Tareq Rahman M, Mohajerani A, Giustozzi F. (2020). Recycling of Waste Materials for Asphalt Concrete and Bitumen: A Review.Materials. Vol 13; 1495: 4-20.

[16] Williams L, (2018).E&T Magazine. Institution of Engineering & Technology. U.K: [cited 30th September 2020]. Available from : https:/eandt.theiet.org/content/articles/2018/09/

[17] Haifang W, Sushanta B, & Ben W.Workshop on alternative binders for Sustainable Asphalt pavement. Transportation Research Board, USA.2012

[18] Nippon slag association, : [cited 26th November 2020]. Available from: https://www.slg.jp/e/slag/

[19] Alternative materials for road construction].;[cited 13th October 2020]. Available from: http://www. constrofacilitator.com