Greenhouse Gas Emission from Asphalt Pavement illustrated Composite Pavement Design with Sustainable Inorganic Mix

A Case Study of Indian Highway Construction

By: Arghadeep Dasgupta
Pune University

Abstract: As the Indian highway system continues to grow in mileage and traffic volume, it is important to construct highways sustainably and with low environmental impact. The construction of asphalt pavement in India has a significant impact on the environment, energy use and greenhouse gas, GHG emissions from asphalt pavement construction have been receiving increasing attention in recent years. In this paper, calculation of GHG emitting out from a Asphalt Pavement project is discussed with a numerical formula along with an illustrated example.

Keywords: *GHG Emission, Asphalt Pavement, Pavement thickness reduction, material saving, CTB / CTSB, Pavement Strain Calculation, Carbon Offset,*

Introduction: As India is having second largest road network in the world and with rapid urbanization population explosion, demand for road network has increased tremendously.

At present, there is no universal criterion for the evaluation of GHG emissions in asphalt pavement construction. This paper proposes to define the system boundaries for GHG emissions from asphalt pavement by using a process-based life cycle assessment method and calculation of Carbon credit with the usage of sustainable alternative pavement technology in terms of material saving, subsequently operation time reduction and reduced level of emission is discussed with illustrated live project.

India has the second-largest road network in the world, spanning a total of 5.89 million kilometers (kms). For highways, asphalt pavement is predominantly used, accounting for over 90%, compared to cement concrete pavement. The asphalt pavement is composed of aggregate, cement, and asphalt binders. The manufacture of the raw materials and construction of asphalt pavements consumes a lot of energy and emits large quantities of greenhouse gases GHGs.

Due to the increasing use of asphalt highways in India, the rapid growth of energy consumption and GHG emissions from its construction has caused rising concern for environmentalist and policy makers, making it necessary to assess the related environment impacts. However, there is a lack of suitable evaluation criteria and benchmark figures in India for GHG emissions generated from asphalt pavement construction.

Composite Pavement Design

There are two conventional pavements, i.e., Flexible pavement and Rigid pavement. Now, composite pavements are also gaining importance and popularity due to scarcity of materials (aggregates, soil and bitumen) and due to the advancement in technologies and most importantly due to their environment friendly output.

Composite pavement is different from the conventional pavements as they provide better levels of performance (both structurally and functionally) and is a better alternative as compared to the conventional flexible and rigid pavements. These conventional pavements are a good option for high volume traffic corridors.

Countries like U.K. and Spain, which have used composite pavement systems in their main road networks, have reported positive experiences in terms of functional and structural performance. These composite pavement structures provide long life pavements, they are environment friendly, releasees less GHG and results into gaining of carbon credit. These pavements offer good serviceability levels and rapid construction with low maintenance operations, which are highly desired, especially for high volume, high priority corridors.

Figure 1: Showing Pavement Treated with Sustainable Solution Mix

For pavement design analysis, as per the codal provision of IRC: 37 – 2012, a Stress Absorbing Membrane Interlayer SAMI along with a reinforcing layer between the BC and the cementitious layer delays the cracks propagating into the bituminous layer drastically. A crack relief layer of wet mix macadam of thickness 100 mm sandwiched between the bituminous layer and the stabilized base layer in arresting the propagation of cracks from the cementitious base to the bituminous layer. Usually, the aggregate layer becomes stiffer under heavier load because of high confining pressure.

Figure 2: Pavement post compaction

With Sustainable Solution mix, a soil stabilizer material having low cement content and forms a slow setting compound causing negligible to fine cracks which gets arrested by the specially designed fibrillated polypropylene fibers. So, Stress Absorbing membrane layer is preferred between the bituminous layer and the stabilized base layer.

The software used for the pavement design analysis is IIT – PAVE software as provided by IRC, which is used for the design to establish the strain values within the specified limits, i.e., the computed strains from the IIT – PAVE software is less than the allowable stains obtained from the equation mentioned in the IRC code for the given traffic and % age reliability.

The sustainable solution is a natural inorganic, powder based eco – friendly pavement material stabilizer that reacts with the soil particles to create layers that are interconnected through a complex interparticle framework. It produces fully bound, impervious and flexible pavement.

Figure 3: Showing Core Drilling at site for testing

It is ferric calcium driven, inorganic, hydration activated and powder-based compound which can be used as an alternative for CTB & CTSB layer. As in the illustration stated in the earlier paragraphs, material productions accounts for major part of the CO2 emission and cement being the major contributor of GHG emission during pavement construction. As per the test result shows that this sustainable mix can be used in a wide range of soils i.e., ranging from fine clay to coarse sand.

Aggregate Reserve of India: Indian aggregate reserve is approximately 100 billion ton and aggregate consumed in the year 2021 was 5.4 billion ton and with this pace of construction aggregate reserve is expected to last for next 20 years. In this situation alternative solution towards sustainable pavement construction is the prime concern and this inorganic mix can be utilized as an sustainable alternative. This method of pavement construction, layer construction requires only the solution mix to be transported to the construction site apart from other conventional materials like aggregates, soil, etc. reducing emission during transportation and saving aggregate drastically. It attains required strength through steady pozzolanic reaction with the in-situ soil.

The main components that are used to formulate this mix are a series of inorganic hydration activated powders. It is composed of a calcium stearate, sodium lignosulphonate, micro silica, hydrated lime, fly ash, ferric red mud & several industrial pozzolanic by product, rate governing additives and PP nano fiber.

Figure 4: Intact Recovered Core as deigned for Lab test

Design Consideration:

The prime objective of the composite pavement design proposal using sustainable solution, is for the determination of the optimum thickness for the proposed location and traffic loadings of the project road. The analysis is being based upon the characteristics of the material, engineering judgment as per the reference of the pavement design manual and guidelines.

Soil Properties:

A geotechnical exploration has been performed for soil which is to be used for the pavement construction work. Samples from the proposed soil query were procured and was tested in the site lab for evaluating original strength and improved engineering properties after treating with the inorganic sustainable mix.

From the wet sieve analysis, it is observed that the soil is heterogeneous mix of different varieties of soil type. As illustrated in the Graph shows the mix proportion of the different types.

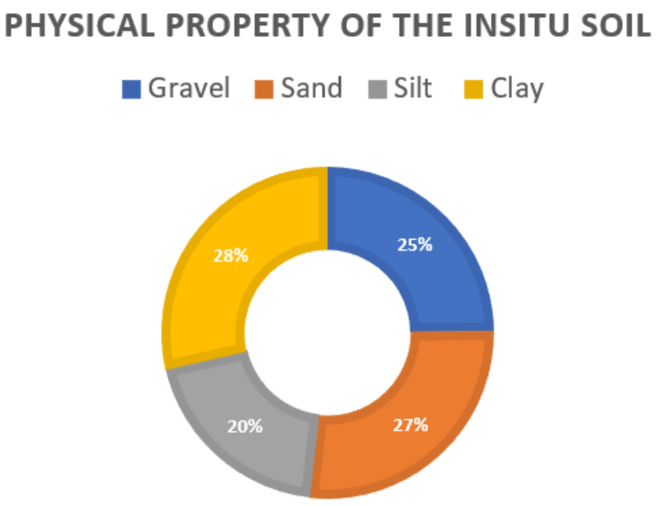

Figure 5: In Situ Soil Composition as per Wet Sieve Analysis

From the wet sieve analysis, it is observed that the soil is heterogeneous mix of different varieties of soil type. As illustrated in the Graph shows the mix proportion of the different types.

Post wet sieving, Liquid & Plastic limits were determined by both cone penetrometer and Casagrande test, results are illustrated in the graph.

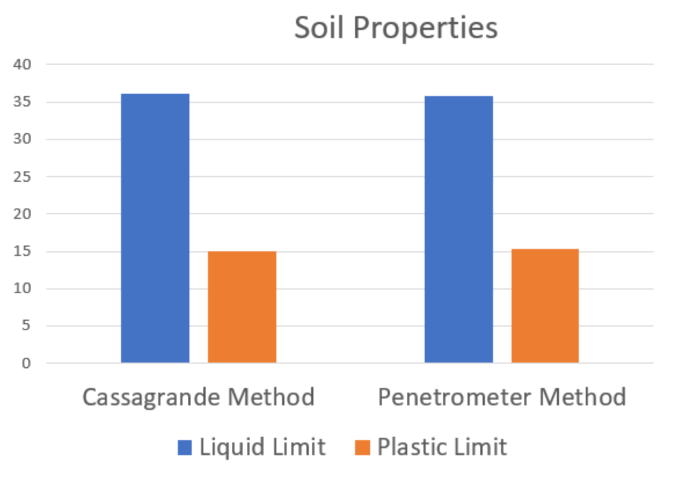

Figure 6: Liquid Limit & Plasit Limit of the Soil

Procter Test was performed to determine the maximum dry density & optimum moisture content of the in-situ untreated soil. Results shows that the MDD is 1.942 g/cc & OMC is 12.26 %.

Then Unconfined Compressive Test was performed on the soil sample casted in a 150mm X 150 mm mould. UCS value of the sample at the end of 28 days is 0.83 Mpa

Post initial experiments and observation, soil samples are mixed with various proportion of designed mix by weight, to determine respective MDD & OMC which is tabulated below:

Sustainable Inorganic Solution Mix	Results
3 %	**OMC = 11.00%** **MDD = 1.932 g/cc**
3.5 %	**OMC = 12.40%** **MDD = 1.914 g/cc**
4 %	**OMC =12.50 %** **MDD = 1.930 g/cc**
4.5 %	**OMC = 12.90 %** **MDD = 1.910g/cc**
5 %	**OMC = 12.40%** **MDD = 1.892g/cc**

Table 1: Showing OMC MDD of Mix Proportion

With the derived OMC, moulds were casted to evaluate the optimum % mix which can be used with the soil by volume for the best result.

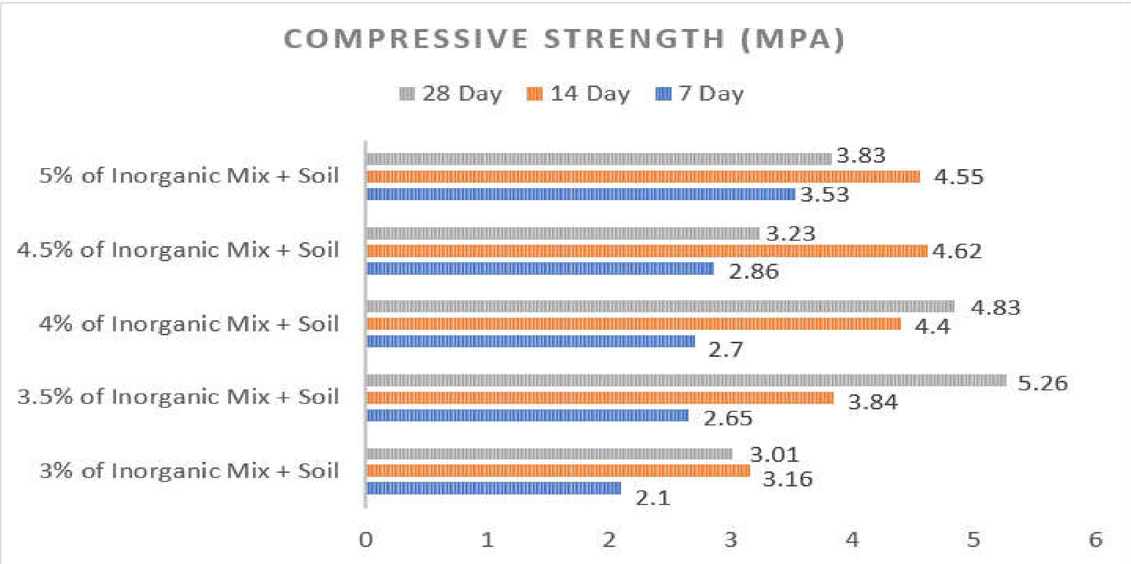

Figure 7: Compressive Strength of the respective Mix design

From the graph above, it is evident that with 3.5% of the organic mix, maximum strength is attained at the end of 28 days, and the pattern of the compressive strength gain shows a progressive trend. So, this mix proportion is chosen for the pavement construction work.

The main purpose of this project report is to propose an alternative pavement design with sustainable solution, along with calculation of CO2 emission from the project, which is prepared to make comparison between the conventional flexible pavements with the alternative pavement design supported by the sustainable technology enhancement

Design Parameters for the pavement is tabulated as shown in the table.

Condition (a) For design traffic = 50 MSA

Layer description	Crust Thickness
Bituminous Concrete layer BC with VG 40 bitumen	40 mm
Dense Bituminous Macadam layer DBM with VG 40 bitumen	60 mm
SAMI with CRMB 60 and 10 mm Nominal Aggregates	1-1.5 kg/sqm.
Stabilized base layer with Sustainable Mix Design	320 mm**
Subgrade with effective design CBR 8%	500 mm
Crust Thickness (mm) till the top of subgrade	420 mm

Table 2: Design properties for the Pavement

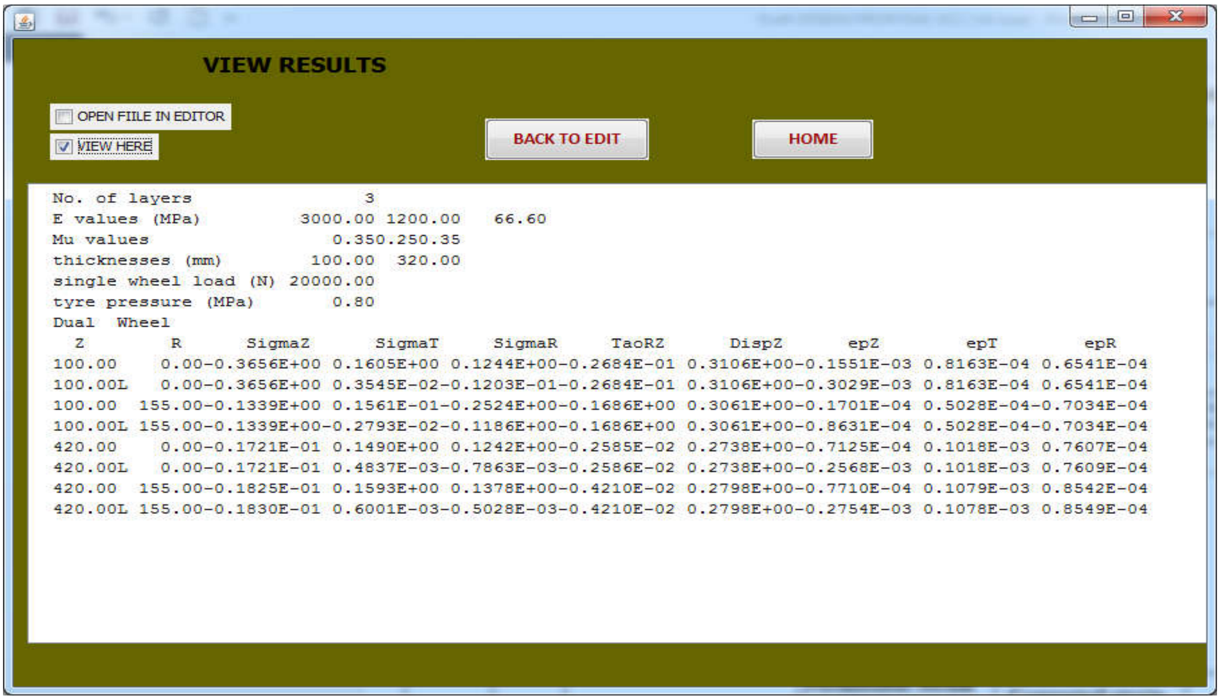

Figure 8: Strain Analysis with IIT Pave Software

Strain Comparison

Sr. No.	Strain Location	Permissible Strain value as per IRC equation (Micro Strain)	Computed strain value observed (Micro Strain)	Remarks
1	Bottom of the Bituminous Layer	178.13	81.63	Safe
2	Bottom of the Stabilized Base	129.86	107.9	Safe
3	Subgrade top	371.69	275.4	Safe

Table 3: Strain Comparison

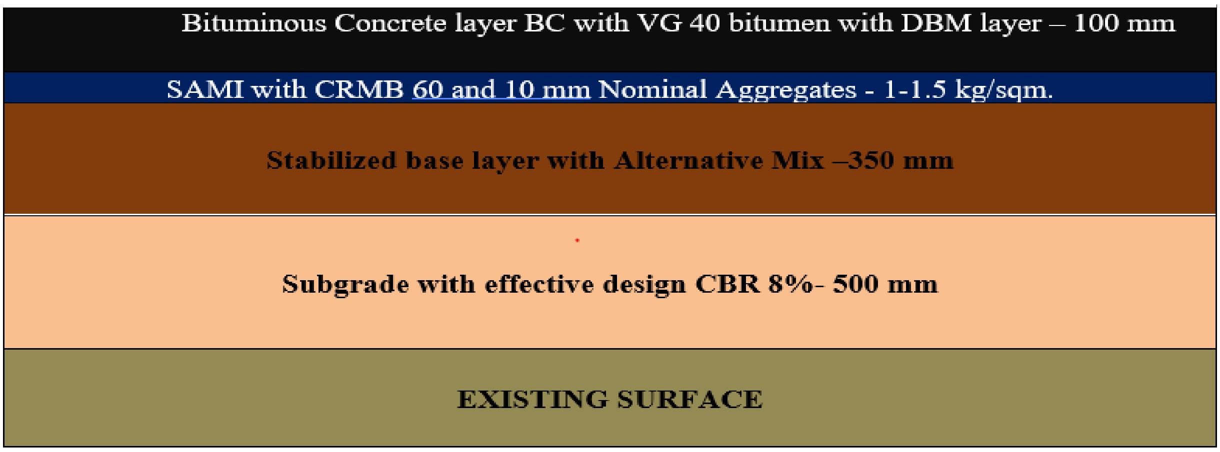

Figure 9: Showing the illustrated Crust composition

Condition (b) For design traffic = 232.5 msa

Layer description	Crust Thickness
Bituminous Concrete layer BC with VG 40 bitumen	50 mm
Dense Bituminous Macadam layer DBM with VG 40 bitumen	100 mm
SAMI with CRMB 60- and 10-mm Nominal Aggregates	1-1.5 kg/sqm.
Stabilized base layer with Sustainable Salt	350 mm**
Subgrade with effective design CBR 8%	500 mm
Crust Thickness (mm) till the top of subgrade	500 mm

Table 4: Design Parameters for Condition 2

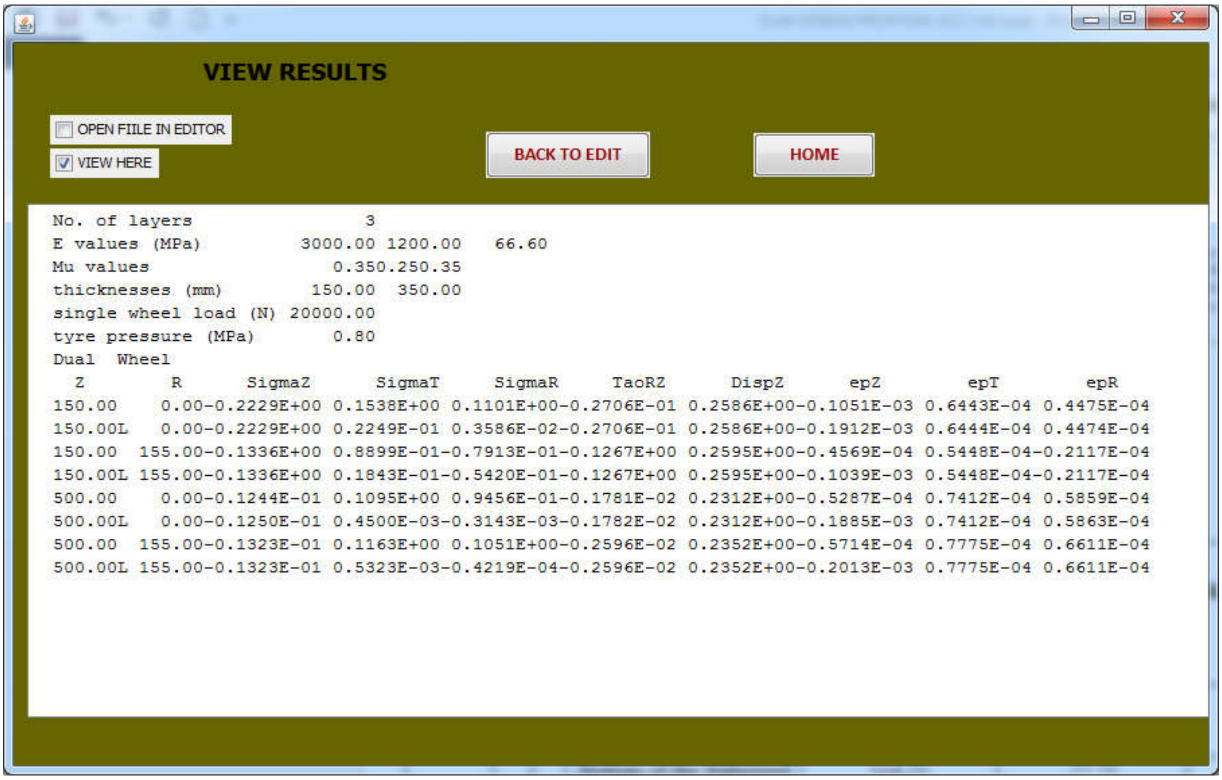

Figure 10: Micro Strain Analysis with IIT Pave Software

Strain Comparison

Sr. No.	Strain Location	Permissible Strain value as per IRC equation (Micro Strain)	Computed strain value observed (Micro Strain)	Remarks
1	Bottom of the Bituminous Layer	119.99	64.43	Safe
2	Bottom of the Stabilized Base	114.25	77.75	Safe
3	Subgrade top	264.83	201.3	Safe

Table 5: Showing the Strain Comparison for Condition 2

SUMMARY SHEET

Layer description	Crust Thickness	Crust Thickness
Traffic in msa	**50**	**232.5**
Bituminous Concrete layer BC with VG 40 bitumen	40 mm	50 mm
Dense Bituminous Macadam layer DBM with VG 40 bitumen	60 mm	100 mm
SAMI with CRMB 60 and 10 mm Nominal Aggregates	1-1.5 kg/sqm.	1-1.5 kg/sqm.
Stabilized Composite Base Layer with Sustainable inorganic mix design	320 mm	350 mm
Subgrade with effective design CBR 8%	500 mm	500 mm
Crust Thickness (mm) till the top of subgrade	420 mm	500 mm

Table 7: Summary Sheet for Design (1) & (2)

S No.	Particulars	Length (m)	Width (m)	Depth (m)	Qty (cum)	Unit
1	BC	600	10.00	0.075	450.00	cum
2	Tack Coat	600	10.00	0.005	30.00	sqm
3	DBM	600	10.08	0.100	604.80	cum
4	Tack Coat	600	10.08	0.008	48.38	sqm
5	Prime Coat	600	10.08	0.006	36.29	sqm
6	WMM	600	10.26	0.250	1539.00	cum
7	GSB	600	13.92	0.200	1670.40	cum
					4378.87	

S No.	Particulars	Length (m)	Width (m)	Depth (m)	Qty (cum)	Unit
1	BC	600	10.00	0.040	240.00	Cum
2	SAMi Layer	600	10.00	0.005	30.00	sqm
3	DBM Layer	600	10.00	0.060	360.00	Cum
4	Stabilised Base with Sustainable compound 4%	600	10.08	0.120	725.76	Cum
5	Stabilised Sub Base 2% of Sustainable compound	600	13.07	0.200	1568.40	Cum
					2924.16	
Overall Material Saving		**33.22**	**%**			

Table 6: Overall Material Saving with Sustainable Solution and Design

From the illustrated summary sheet above, it is evident that there is a material saving with the Sustainable design. The more material saved, the project is more sustainable with greater Carbon offset.

To have better comparative understanding with Conventional method of Pavement design and execution with the pavement design treated with doses of sustainable compound illustrated in the table, with marginal usage of aggregate, 10% or less and in-situ soil, we have considered a patch of 600 m stretch, with 10m width carriageway. Tested parameters are considered for design analysis with IIT pave software and strain calculation based on IRC 37-2017. Post calculation and analysis, it is estimated that, there is a material saving of 33.2%.

Numerical Formula to Calculate Green House Gas Emission

Asphalt pavement construction has a significant impact on the native environment, in terms of h energy use and GHG emissions. Thus, GHG emission from pavement construction has drawn lots of attention worldwide in terms of emission regulation and alternative design solution. This research and calculation based on the data from Key Laboratory Special Area Highway Engineering of Ministry of Education, Changlong University, show that the greenhouse gas emissions from the mixture mixing phase are the highest, account for about 54% of the total GHG emission.

The simplified expression of a GHG emission, (GHG_{emsn}), which is the outcome of all the activities, work breakdown units (WBU) of any project which results into CO2 emission and emission factor (EF), shown as in the equation below.

$$GHG_{emsn} = A_{wbu} \times EF$$

Equation 1: Calculation of Greenhouse Gas Emission

…………… Eq (1)

While carbon dioxide is the GHG of greatest concern, there are several other GHGs. As the global warming potential (GWP) of these GHGs varies, a group of conversion coefficients are established to convert the emission of a specific GHG into carbon dioxide equivalents (CO2e). In this context, GWP is the integral of the global warming effect of a GHG compared with that of CO2 in the same time interval, commonly using a time horizon of 100 years. The 100-year GWPs of CO2, CH4 and N2O are 1, 23 and 296 respectively. Therefore:

$$CO_{2emsn} = A_{wbu} \times EF \times GWP$$

Equation 2: CO2 Emission calculation

……………. Eq (2)

The carbon account of asphalt pavement is the sum of all relevant emission sources, so the final expression of the asphalt pavement's carbon footprint can be given by Equation (3):

$$GHG_{emsn} = (CO_{2emsn}) = \sum_{i}^{n} [(Awbu\ i \times EFi \times GWPi)] + [(Cum.Emsn)K]$$

Equation 3: Innovative GHG Emission from Pavement

where $(CO2_{emsn})i$ means the carbon emission from the process of Asphalt pavement and CumEmsn is the cumulative emission of carbon over the life cycle of the pavement.

$$Cum_{Emsn} = \sum_{1}^{3} [(CO2emsnAC) + (CO2emsnM)]$$

Equation 4: Cumulative CO2 emission equation from Pavement

……………Eq (4)

$CO_{2emsn}AC$ emission of greenhouse gasses post construction activities are over & $CO_{2emsn}M$ emission of greenhouse gasses during the act of periodical repair and maintenance work within that period if required.

As per the study conducted by Department of Energy, Office of Scientific & Technical Information, its is observed that post completion of pavement construction and laying operation there is a continual emission GHG for a certain period. Later it is observed to be negligible. Major emission happens during the broad day light, and it becomes marginally negligible during the night and in low daylight. This trends generally continues till 1st to 4th week of construction activities at peak and gradually diminishes within 3rd year of operation.

Energy Consumption Assessment During Pavement Construction

Most pavement construction activities are carried out with heavy machinery and equipment. The GHG emissions of asphalt pavement consists of those from the machines and equipment used in the construction process. It is calculated by multiplying the energy consumption (EC) by the emission factor (EF) of each energy type, fuel, or electricity, as shown below.

$$GHG_{emsn} = EC \times EF$$

Equation 5: To calculate Energy Consumption

……………… Eq (5)

Analysis shows that the greenhouse gas emissions from the mixture mixing phase are the highest, and account for about 54% of the total amount. The second highest GHG emission phase is the production of raw materials. For GHG emissions of cement stabilized base/subbase, the production of raw materials emits the most, about 98%. The GHG emission for cement production alone is about 92%. If cement treated layer are used for the preparation of CTB & CTSB, huge quantity of GHG is contributed from the pavement construction. The research analysis proposes that to control GHG emissions from asphalt pavement considerable focus should be concentrated on the selection of alternative material which produces lesser GHG and optimum use of materials. At the material manufacturing stage, proper care should consider, selection of alternative material & methods, to replace cement from CTB & CTSB should be adopted. Reinforcing BC course and providing a reinforcement layer will marginally reduce the formation of tension crack and propagate to the surface and in turn reduce the Lifecycle emission factor. Alongside proper measure to reduce GHG emissions during the mixture mixing stage should be also considered.

Discussion and Recommendations

The results indicate that the raw materials production phase and the mixture mixing phase contribute to the most GHG emissions for the asphalt mixture course. Whether considering the cement production or not, the raw materials production phase contributes to the most GHG emissions for the cement stabilized aggregate courses. The use of raw materials with low GHG emissions and increasing the efficiency of asphalt mixing equipment are good starting points to reduce energy consumption and GHG emissions. The warm or cold asphalt mixture can be helpful to decrease the GHG emissions. In addition, emulsion asphalt could be a good choice to reduce the GHG emission. The benefit of using reclaimed asphalt pavement RAP is the reduced extraction and production of virgin aggregates, so this method must be adopted wherever and whenever possible.

Due to the large amount of cement used as raw material in the base and subbase, although the energy consumption of asphalt surface layer is high, its GHG emissions are relatively low. When the raw materials are not considered, the energy consumption of the asphalt surface layer is the

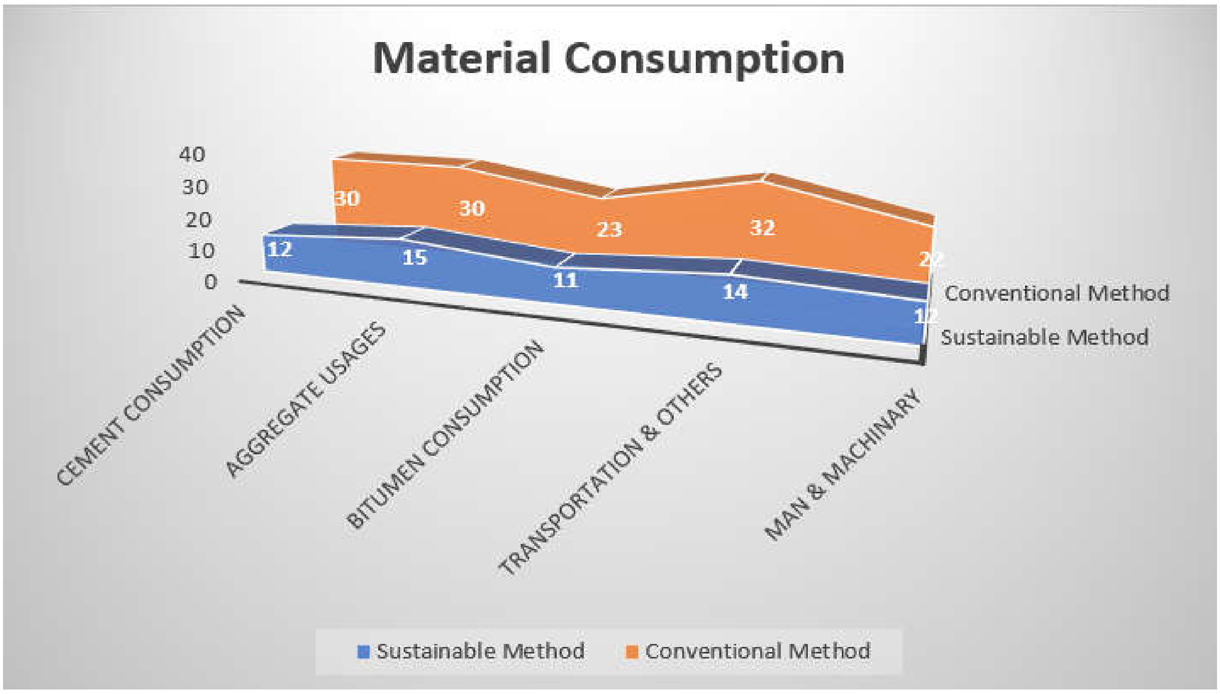

Figure 11: Comparison of Material Consumption

largest, and the energy consumption and emissions of cement stabilized aggregate base ort subbase are relatively small.

Therefore, in the design of the asphalt surface courses, the focus should be the control of energy consumption, the use of energy–efficient equipment and the optimization of the construction material and management. In the design of cement stabilized aggregate base or subbase, the focus should be to decrease the GHG emissions from the raw materials production. The use of high efficiency and energy saving methods of cement production can achieve the purpose of energy saving and emission reduction.

Alternatively, as illustrated in the example discussed above, the use of alternative inorganic mix to replace use of cement and aggregate, its observed that on an average, we can marginally reduce the usage of cement to be used for CTB & CTSB layer, aggregate, bitumen, employment of man & machinery, transportation of construction material and hauling etc. It is illustrated as in the graph below.

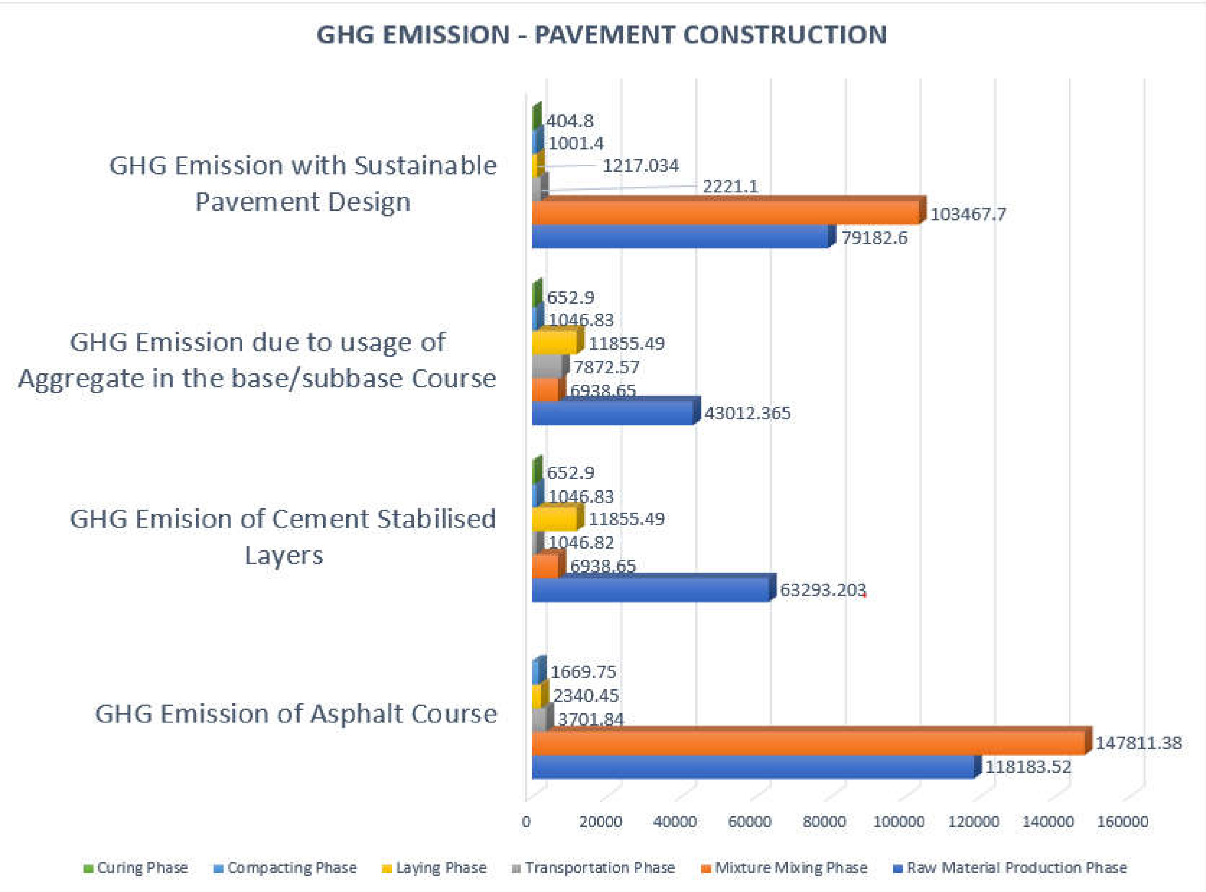

Figure 12: Showing GHG Emission from various Phases of Pavement Construction

From the graph above, the GHG emission for a stretch 600m and 10m wide stretch, CO2 emitted from during the course of operation is roughly calculated as, during the material production phase and mixing phase to be 79,182.6 kg & 103,467.7 kg respectively.

Comparing the same stretch with conventional method, CO2 will supposedly be emitted to be 118,183.52 kg & 147,811.38 kg respectively. We have considered these two factors in our calculation as they constitute roughly up to 98% of total GHG emission.

Comparing the two above calculation it can be derived that, with the sustainable solution there is a Carbon offset of 83344.6 Kg, which can be utilized against the projects which seek carbon credit and set a benchmark for the project of similar kind across the country.

Conclusion: The prime objective of the composite pavement design proposal using sustainable solution, is for the determination of the optimum thickness for the proposed location and traffic loadings of the project road. The analysis is being based upon the characteristics of the material, engineering judgment as per the reference of the pavement design manual and guidelines. As per the prime objective of the project, it depicts the alternative pavement solution as a live case study along with the calculation of CO2 emission from the project, which is prepared to make comparison between the conventional flexible pavements with the alternative pavement design supported by the sustainable technology enhancement

With the illustrated formulation above in the report, quantity of GHG emission from a Asphalt Pavement work can be calculated and with sustainable composite pavement design and execution the reduced quantity of the GHG can be calculated which will result in to carbon offset which can be utilized in the emerging multi billion market of Carbon Credit and its realization worldwide.

Acknowledgement: This paper is an outcome of the research done by the author on self-prescribed solutions & experience from the site execution relating to the topic under study. However, this original work has been most ably aided by secondary sources where works of other authors have been used and cited in the text wherever necessary. We gratefully acknowledge their contribution to our research endeavor.

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