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Carbon Footprints Assessment of RBI Grade 81 Stabilized Pavements using Life-Cycle Approach

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Abstract

Objectives: To reduce the life-cycle carbon footprint of a flexible pavement using RBI grade 81, a patented natural soil stabilizer. **Methods:** This paper outlines the common guidelines for estimation of greenhouse gas emissions associated with a pavement as per the Indian environmental conditions. California Bearing Ratio (CBR) tests were carried out on subgrade soil treated with diverse proportions of RBI grade 81. Greenhouse gas emissions due to the initial construction phase and maintenance activities over a 20 year life cycle were assessed and compared for RBI grade 81 treated and non-treated subgrades. Key sources of carbon footprint considered were construction materials and transportation with construction equipments having negligible contribution. **Findings**: Studies reveal significant improvement in the CBR of the subgrade soil leading to reduction of pavement layer thicknesses thereby limiting the requirements of resources that is to say materials, fuel and machinery. The total CO_2 emissions were reduced from 910.9 tonnes to 750.8 tonnes per km length of a four lane dual carriageway road by treating the subgrade soil with 4% RBI grade 81. The production of materials and transportation used to construct the project account for 93% and 7% of the total CO_2 emissions throughout the life cycle of the pavement. **Improvements:** Use of RBI grade 81 results in attenuation of greenhouse gas emissions which were found consequential in amassing of carbon credits, a step towards safeguarding the environment for the future generations to come.

Keywords: California Bearing Ratio, Greenhouse Gas Emissions, RBI Grade 81, Subgrade Stabilization

1. Introduction

The exponentially growing population of India has led to an enormous practice of construction activities since the last decade. Construction practices require materials, machineries and fuel leading to greenhouse gas emissions which severely deteriorate the environment, alarming us to take immediate steps aiming at its preservation. Environmental preservation could be best understood as limiting the consumption of natural resources in construction practices. Environmental preservation requires finding new sustainable materials which can reduces the requirements of natural resources like aggregates and bitumen in the construction industry. Road Building Index (RBI) grade-81 is a patented natural soil stabilizer marketed by Alchemist Technology Limited, New Delhi in India. This study aims to reduce greenhouse gas emissions throughout the life cycle of a flexible pavement by treating the subgrade layer of a flexible pavement with RBI grade 81 as it reduces the pavement thickness by enhancing the California Bearing Ratio (CBR) of the subgrade soil. This paper focuses on

- To draw a methodology for determining greenhouse gas emissions due to the utilization of construction materials based on the Indian specific studies.

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- To draw a methodology for determining greenhouse gas emissions due to the vehicles (trucks) used for transportation of construction materials.
- To reduce the greenhouse gas emissions emitted during the life cycle of a flexible pavement in India by treating its subgrade layer with RBI grade 81.

2. Materials used

Key materials used in this study were RBI grade 81 and subgrade soil.

2.1 RBI Grade 81

RBI grade 81 is an inorganic natural soil-stabilizer, which alters the strength characteristics of soil providing an exclusive, inexpensive, environment welcoming solution for weak subgrade soils forming a tough and permanent layer, showing satisfactory performance under undesirable temperature conditions ranging from very elevated temperatures to freezing low temperature conditions, and applicable to all kinds of subgrade soils. RBI grade 81 was initially made for South African Army Road Building International in the starting of 1990's for its application in construction practices. The use of RBI grade 81 leads to alteration of the following elements:

- Decrease in the period of construction to almost 40%.
- Significant enhancement of the performance and structural strength of roads.
- Nullification of the adverse effect of moisture on soils preventing damage to the road subgrade foundations.
- Decrease the consumption of natural resources.
- Decrease the earth-moving and transportation costs to almost 60%.
- Enhance the life cycle span of the pavement by decreasing the cost associated for its maintenance.

The physical and chemical properties[1] of RBI grade 81 are listed in Table 1 and 2 respectively.

2.2 Subgrade Soil

In the present work, the soil was collected from a road construction site situated in Chandigarh, India. According to the Indian Standard Classification System[2] the soil was classified as clay with low plasticity (CL). Index properties[3-6] of subgrade is tabulated in Table 3

Table 1. Physical properties of RBI grade 81

Physical Properties	
Odour	Odourless
pH	12.5 (Saturated paste)
Specific Gravity	2.5
Solubility in water	0.2 pts/ 100 pts
Freezing point	None, Solid
Flammability	Non-flammable
Shelf life	12 months (dry storage)
Storage	Dry storage
Bulk density	700 kg/m^3

Table 2. Chemical properties of RBI grade 81

Chemical Properties	Chemical Composition (%)
CaO	52-56
SiO_2	15-19
SO_3	9-11
Al_2O_3	5-7
Fe_2O_3	0-2
MgO	0-1
Mn, K, Cu, Zn	0-3
Polypropylene Fibre	0-1
Additives	0-4

Table 3. Properties of soil

Properties	Soil
Specific Gravity	2.62
Gravel (%)	0
Sand (%)	20.8
Silt (%)	64.7

Clay (%)	14.5
Liquid Limit (%)	29.8
Plastic Limit (%)	20.7
Plasticity Index	9.1
I.S. Classification	CL

3. Study Methodology for Estimation of Carbon Footprints

The major aim of this study was to establish a methodology for estimation of carbon footprint associated with flexible pavements based on Indian specific studies. Road construction engages utilization of materials, transportation and machinery thereby releasing air polluting greenhouse gas in the atmosphere. Greenhouse gas emissions are sourced from the following mentioned constituents of road construction:

- Utilization of construction materials predominantly being bitumen and aggregates.
- Haulage of construction material from the plants/quarries to the construction site.
- Construction machineries used at site for preparing and laying the material mixes.

3.1 Methodology for Estimation of Carbon Footprint due to Construction Materials

Road construction utilizes bitumen, aggregates and soil resulting in release of greenhouse gas emissions in the atmosphere. Production of majorly all the construction materials is an energy absorbing course of action that leads to carbon dioxide (CO_2) emissions termed as embodied CO_2, though these materials may not have any emissions during their on-site utilization. Since the past decade in India, researchers have worked on determining embodied CO_2 values for different construction materials. Due to the diverse construction and manufacturing practices in India, lack of data collection and surveillance came out as the main stumbling blocks with regard to the embodied energy and CO_2 calculations associated with the construction industry. In the recent years, some institutes and researchers have put in effort on establishing embodied energy and CO_2 values for commonly used materials during the construction processes. Since the amount of such studies is minute, researchers don't have much choice for the selection of embodied CO_2 values. After an intensive literature review on the subject, the analysis of embodied energy and CO_2 done by Auroville Earth Institute[7] (AEI) were found most comprehensive and significant. The study estimates India specific embodied energy and CO_2 values for a wide range of construction materials prevalent in India. The extent of embodied energy and CO_2 values taken in account from the study caters CO_2 emissions due to:

- Raw material extraction
- Processing of raw materials to produce finished material

In case, embodied energy and CO_2 factors were not obtainable from the study carried out by AEI for some materials, international literature was refereed for the same[8]. Embodied CO_2 of various construction materials is presented in Figure 1.

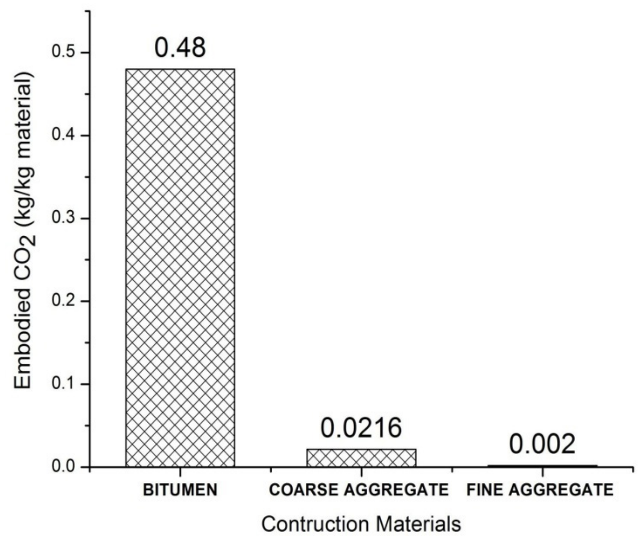

Figure 1. Embodied CO_2 of construction materials.

As per the guidelines issued by the Indian Road Congress (IRC) for design of flexible pavements in India[9], a granular flexible pavement comprises of three layers, starting from the top, bituminous layer comprising of bituminous concrete (BC), followed by dense bituminous macadam (DBM). Bituminous layer is followed by granular layer comprising of wet mix macadam (WMM) followed by granular sub-base (GSB). The subgrade layer forms the third layer serving as the foundation of the pavement. Construction of these layers involves significant utilization of materials. Key materials consumed for road construction include:

- Bitumen
- Coarse aggregate
- Fine aggregate

Based on the Ministry of Road Transport & Highways (MoRT&H), Specifications for road and bridge works (Fifth Revision)[10], the layers of flexible pavement were designed for various proportions of bitumen and aggregates. Carbon emissions released due to construction of a unit cubic metre of different layers of flexible pavement were calculated and presented in Figure 2.

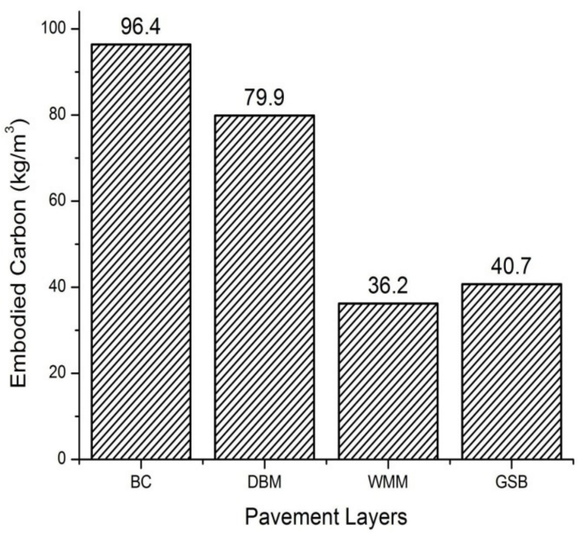

Figure 2. Total CO_2 embodied in 1 m^3 of mix of various pavement layers.

These results can be used to estimate the carbon emissions of any flexible pavement section with known layer thicknesses based on the CBR of subgrade and the design traffic which the pavement would have to cater in its design life.

3.2 Methodology for Estimation of Carbon Footprint due to Transportation of Construction Materials

Construction materials need to be transferred from their source of production to the road construction sites requiring transportation facility provided by freight vehicles of various payload capacities. Transportation sector forms one of the primary sources of air pollution due to emissions by vehicular operations. A study conducted by India greenhouse gas program released India specific road transport emission factors[11] for different categories of vehicles in India. The report illustrates the methodology to arrive at country (India) specific emission factors so as to help the Indian corporate to strengthen its greenhouse gas accounting process based on fuel efficiency and gross weight of freight vehicles. The freight vehicles were classified in three categories of low, medium and high duty vehicles based on their payload capacity. Table 4 denotes the emission factors for various freight vehicles in India.

Table 4. Emission factors of freight vehicles

Category	kg CO_2/km
Low Duty Vehicles (payload capacity <3.5 Tonnes)	0.3070
Medium Duty Vehicles (payload capacity <10 Tonnes)	0.5928
Heavy Duty Vehicles (payload capacity >12 Tonnes)	0.7375

3.3 Methodology for Estimation of Carbon Footprint due to Construction Machinery

Carbon footprint due to construction machinery has been ignored in this study as literature review suggests insignificant contribution (less than 1 percent) due to construction machinery[12].

4. Result and Discussion

4.1 Experimental Investigations using RBI Grade 81

A series of laboratory investigations were carried out so as to find out the improvement in strength parameters of subgrade soil classified as clay of low plasticity when treated with RBI grade 81. RBI grade 81 was dealt in variable percentages ranging from 1% to 4% with an increment of 1%.

4.1.1 Modified Proctor Compaction Tests

On performing modified proctor compaction tests[5] using variable dosage of RBI grade 81 treated subgrade soil the authors examined a uniform falling trend in the maximum dry density (MDD) and a smooth rise in the optimum moisture content (OMC) as shown in Figure 3-4. This behaviour could be justified by the fact that presence of polypropylene fibre in RBI grade 81 possessing lower specific gravity reduces the MDD of soil mixture whereas the higher water absorption could be accounted due to the presence of calcium hydroxide in RBI grade 81.

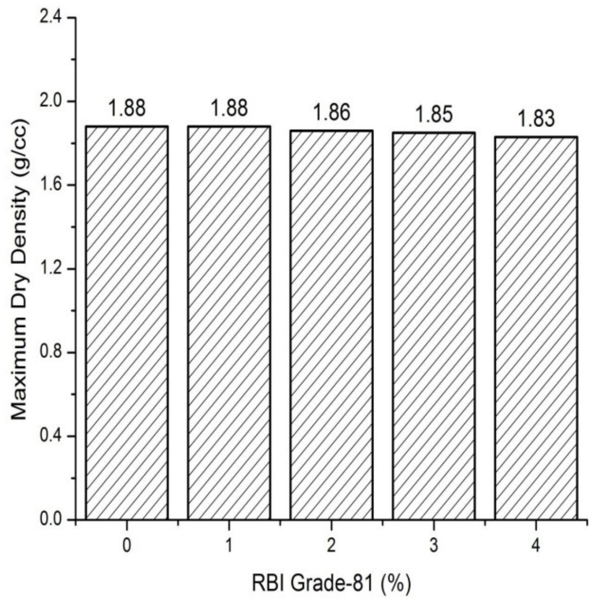

Figure 3. Variation in MDD with varying RBI grade 81 content.

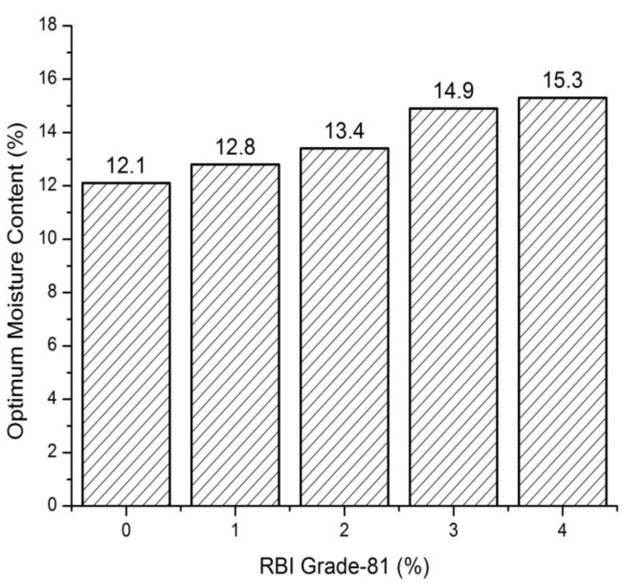

Figure 4. Variation in OMC with varying RBI grade 81 content.

4.1.2 CBR Tests

Samples prepared for CBR tests[6] were cured for seven days before soaking them in water for four days. Curing is necessary as RBI grade 81 is a hydration activated powder based stabilizer leading to formation of cementitious compounds. Intensive laboratory testing on variable stabilizer proportions for soaked CBR tests resulted in a rise from 3.2% to 24.2% at a proportion of 4% RBI grade 81 and 96% subgrade soil mix as presented in Figure 5.

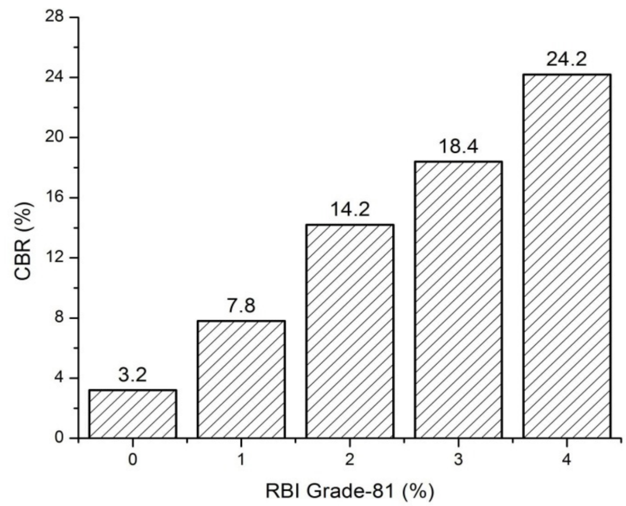

Figure 5. Variation in CBR with varying RBI grade 81 content.

As the thickness of different layers of pavement overlying the subgrade are inversely dependent upon the CBR value of the subgrade, its treatment with RBI grade 81 would lead to reduction in pavement layer thicknesses thereby leading to savings in construction materials and their transportation requirements.

In the present study, carbon footprint associated with 20 year life cycle of a pavement comprising of initial construction phase and a 5 yearly periodic maintenance phase were estimated for RBI grade 81 treated and non-treated subgrade. The detailed discussions and analysis of the results obtained are given in the following sections.

4.2 Design of Flexible Pavements

RBI grade 81 treated subgrade characterizes higher CBR resulting in thinner pavement layers. The road section considered for the present study comprises of a length of 1 km with a width of 21 metres distributed among its 4 lanes which would cater a traffic intensity of 10 million standard axles. Figure 6 depicts the thickness of various layers of flexible pavements for RBI grade 81 treated and non-treated subgrade.

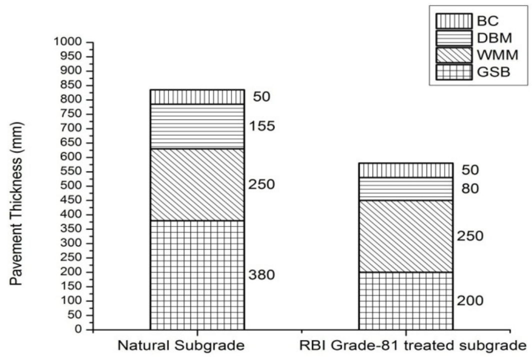

Figure 6. RBI grade 81 stabilized and non-stabilized pavement sections.

4.3 Estimation of CO_2 Emissions Associated with the Initial Construction Phase of RBI Grade 81 Treated Flexible Pavements

Carbon footprint due to the transportation of construction materials would be significantly dependent upon the distances between the construction site, the stone quarries for aggregates and the petroleum refineries for obtaining bitumen. Hence, an assumption of a lead distance of 50 km has been adopted for all materials carried by a medium duty vehicle type truck having a payload capacity of 10 tonnes. Carbon footprint due to utilization and transportation of material required during the initial construction phase for RBI grade 81 treated and non-treated subgrade has been presented in Figure 7 and it depicts appreciable drop in carbon footprint of RBI grade 81 treated subgrade as compared to the natural subgrade.

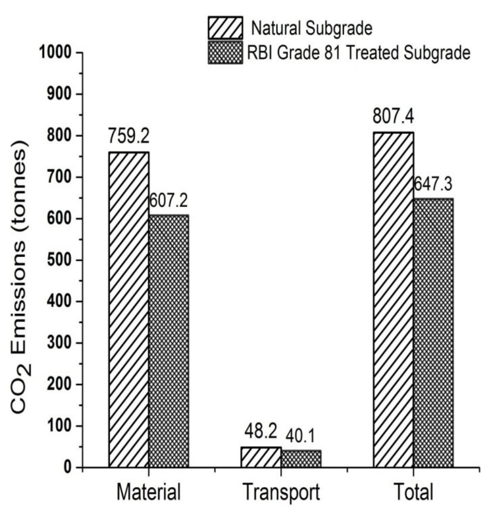

Figure 7. CO_2 emissions emitted during the initial construction phase of construction of a unit km length of road.

4.4 Estimation of CO_2 Emissions Associated with Maintenance Phase of RBI Grade 81 Treated Flexible Pavements

A flexible pavement needs periodic maintenance in order to maintain its serviceability. Periodic maintenance for bituminous roads comprises of laying of a renewal coat to the wearing surface at a predestined rate of recurrence that is generally obtained on the basis of the expected traffic. Based on literature review and inputs from site engineers and contractors, a bituminous overlay of 40 mm thickness was proposed with a periodicity of 5 years. Figure 8 depicts the CO_2 emissions released while performing the four maintenance work cycles during the complete life cycle of 20 years for a pavement.

Since, maintenance activities are dependent on wear and tear of the top bituminous layer and not on the CBR of the subgrade, RBI grade 81 treatment does-not results in any reductions in carbon footprint throughout the maintenance period of pavement's life cycle.

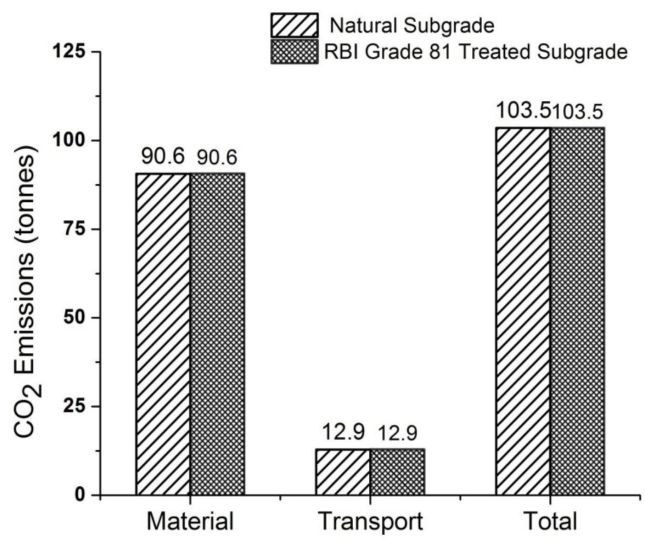

Figure 8. CO_2 emissions emitted during the maintenance phase of construction of a unit km length of road during its life cycle of 20 years.

4.5 Estimation of CO_2 Emissions Associated with the Life Cycle of RBI Grade 81 Treated Flexible Pavements

Combining the carbon footprint due to initial construction and maintenance phase, the life cycle assessment of associated carbon footprint has been presented in Figure 9.

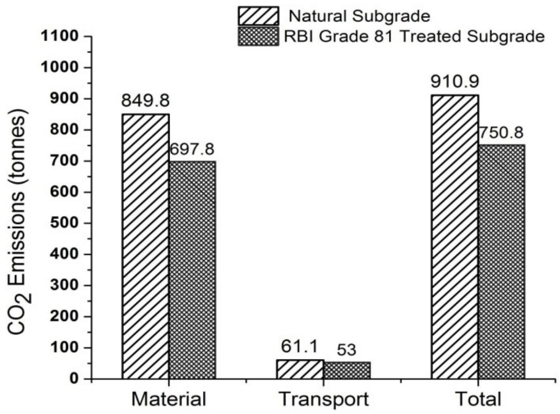

Figure 9. CO_2 emissions emitted during the life cycle (20 years) of a pavement of a unit km length.

The authors observed a significant difference in the CO_2 emissions for the complete life cycle of a pavement when compared with the initial construction phase. The life cycle approach has been accepted as a robust method of computing the carbon footprint of a flexible pavement. Figure 10 shows the percentage reduction in CO_2 emissions due to materials and transportation of construction materials during the life cycle of a flexible pavement. RBI grade 81 treatment shows 17.6% reduction in CO_2 emissions during the complete life cycle of the pavement.

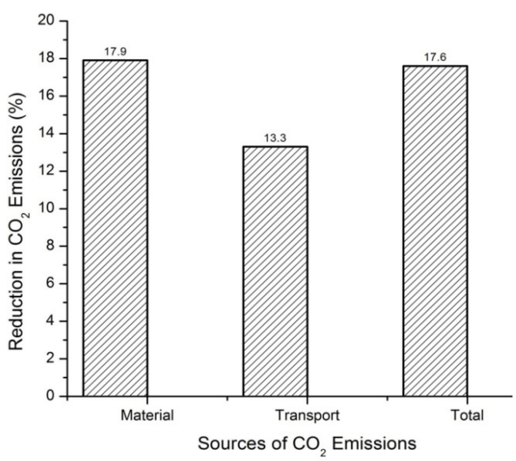

Figure 10. Percentage reduction in CO_2 emissions during the life cycle of RBI grade 81 treated pavements.

5. Carbon Credits- A Green Approach for Subgrade Stabilization

Kyoto Protocol[13] was signed by various countries aiming upon practicing methods to reduce their CO_2 emissions. Reduction of one tonne of CO_2 yields one carbon credit, treated universally as a global trading currency. Quantification of benefits of RBI grade 81 stabilization was evaluated in terms of earning carbon credits. One carbon credit caters an equivalent international value of 24 euro[14]. Figure 11 depicts a gain of 160 carbon credits gained due to the stabilizing effect of RBI grade 81.

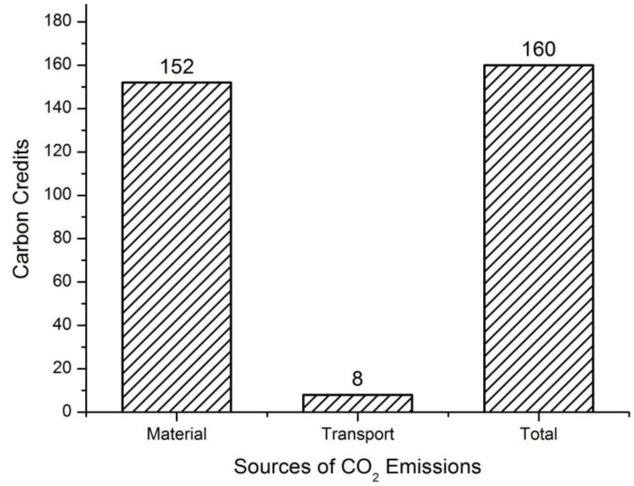

Figure 11. Carbon credits gained during the life cycle of RBI grade 81 treated pavements.

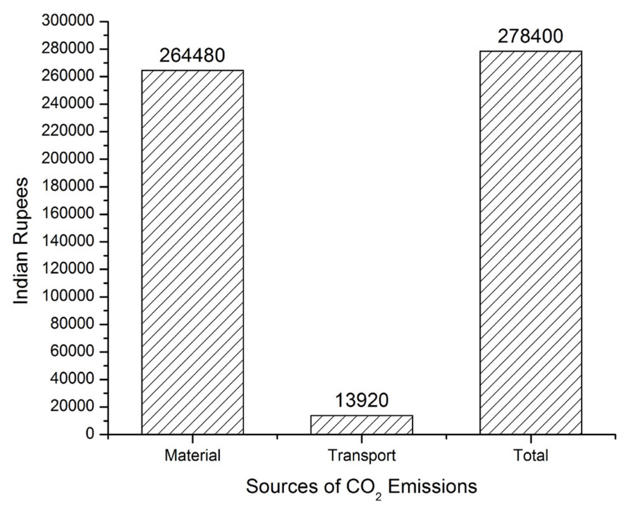

Figure 12. Equivalent international value of carbon credits gained in Indian rupees during the life cycle of RBI grade 81 treated pavements.

Figure 12 portrays the equivalent international value of carbon credits gained during the life cycle of a flexible pavement amounting to ₹ 278400. Analytical results obtained from experimental findings show reduction in carbon emissions resulting in growth of carbon credits, hence helping in developing a sustainable environment.

6. Conclusion

A noteworthy enhancement of CBR was observed from 3.2% to 24.2% by treating the subgrade soil with an optimized dosage of 4% RBI grade 81. Application of RBI grade 81 in subgrade layer minimizes pavement layer thicknesses reducing the requirement and associated transportation of construction materials. The total CO_2 emissions were reduced from 910.9 tonnes to 750.8 tonnes per km length road of dual carriageway type leading to gain of 160 carbon credits of amounting to ₹ 278400. Production of materials and transportation used to construct the project account for 93% and 7% of the total CO_2 emissions throughout the life cycle of the pavement. As compared to the initial construction phase emissions, life cycle analysis reveals a noteworthy difference in emissions prompting the importance of the approach.

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