ECO-FRIENDLY PAVEMENT SOLUTIONS: ANALYSIS OF ROADS CONSTRUCTED WITH PLASTIC WASTE

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ABSTRACT

The rapid increase in plastic waste has posed a significant threat to environmental sustainability and public health. To address this issue, civil engineers have explored innovative methods to incorporate plastic waste into infrastructure development. This paper presents a comprehensive analysis of plastic-modified road construction, evaluating its feasibility, structural performance, and environmental benefits. The study investigates the integration of shredded plastic waste into bituminous mixes used for road paving, emphasizing improvements in durability, strength, and water resistance. Laboratory tests such as Marshall Stability, flow value, and fatigue life assessment were conducted to compare plastic-modified asphalt with conventional bitumen mixtures. The results show enhanced load-bearing capacity and longevity of plastic roads, along with significant potential for waste reduction and sustainable development. This eco-friendly approach offers a dual benefit—addressing plastic pollution while improving road infrastructure performance, making it a promising alternative for future highway and urban road projects.

1. INTRODUCTION

1.1 General

Plastic pollution is one of the most pressing environmental challenges of the 21st century, with millions of tons of non-biodegradable waste accumulating annually in landfills and natural ecosystems. Simultaneously, the demand for long-lasting and cost-effective road infrastructure is growing rapidly, especially in developing countries. The intersection of these two issues has led researchers to explore sustainable engineering practices that can repurpose plastic waste in construction.

Plastic road construction is an innovative solution that utilizes processed plastic waste as a partial replacement for bitumen in asphalt mixtures. This approach not only improves the properties of traditional road materials but also contributes to reducing the environmental impact of plastic disposal. When plastic is incorporated into hot bituminous mixtures, it enhances the binding properties, elasticity, and thermal resistance of the pavement.

This paper aims to evaluate the design methodology, material composition, and mechanical performance of plastic-enhanced pavements. It also discusses the environmental implications, economic feasibility, and challenges involved in adopting this technology on a large scale. By presenting empirical data and real-world case studies, the paper advocates for integrating plastic waste into mainstream road construction practices as a viable path toward greener infrastructure.

1.2 Plastic

A material that contains one or more organic polymers of large molecular weight, solid in its finished state and at some state while manufacturing or processing into finished articles, can be shaped by its flow, is called as ‘Plastic’. Plastics are durable and degrade very slowly; the chemical bonds that make plastic so durable make it equally resistant to natural processes of degradation. Plastics can be divided in to two major categories: thermoses and thermoplastics. A thermoset solidifies or "sets" irreversibly when heated. They are useful for their durability and strength, and are therefore used primarily in automobiles and construction applications. These plastics are polyethylene, polypropylene, polyamide, polyoxymethylene, polytetrafluorethylene, and polyethyleneterephthalate. A thermoplastic softens when exposed to heat and returns to original condition at room temperature. Thermoplastics can easily be shaped and moulded into products such as milk jugs, floor coverings, credit cards, and carpet fibres. These plastic types are known as phenolic, melamine, unsaturated polyester, epoxy resin, silicone, and polyurethane. According to recent studies, plastics can stay unchanged for as long as 4500 years on earth with increase in the global population and the rising demand for food and other essentials, there has been a rise in the amount of waste being generated daily by each household. Plastic in different forms is found to be almost 5% in municipal solid waste, which is toxic in nature. It is a common sight in both urban and rural areas to find empty plastic bags and other type of plastic packing material littering the roads as well as drains. Due to its biodegradability it creates stagnation of water and associated hygiene problems. In order to contain this problem experiments have been carried out whether this waste plastic can be reused productively. The experimentation at several institutes indicated that the waste plastic, when added to hot aggregate will form a fine coat of plastic over the aggregate and such aggregate, when mixed with the binder is found to give higher strength, higher resistance to water and better performance over a period of time. Waste plastic such as carry bags, disposable cups and laminated pouches like chips, pan masala, aluminium foil and packaging material used for biscuits, chocolates, milk and grocery items can be used for surfacing roads. Use of plastic along with the bitumen in construction of roads not only increases its life and smoothness but also makes it economically sound and environment friendly. Plastic waste is used as modifier of bitumen to improve some of bitumen properties Roads that are constructed using plastic waste are known as Plastic Roads and are found to perform better compared to those constructed with conventional bitumen.

India's consumption of Plastics will grow 15 million tonnes by 2015 and is set to be the third largest consumer of plastics in the world. Various activities like packing consume almost 50-60% of the total plastics manufactured .Plastic offer advantages lightness, resilience, resistance to corrosion, colour, fastness, transparency, ease of processing etc.The plastic constitutes two major category of plastics based on physical properties; (i) Thermoplastics and (ii) Thermo set plastics. The thermoplastics, constitutes 80% and thermo set constitutes approximately 20% of total postconsumer plastics waste generated .In a thermoplastic material the very long chain – like molecules are held together by relatively weak Van der Waals forces. In thermosetting types of plastics the molecular are held together by strong chemical bonds making it quite rigid materials and their mechanical properties are not heat sensitive.

1.2.1 Role of plastic or polymer in pavement

Modification of BC, with the synthetic polymer binder can be considered as a solution to overcome the problems, arising because of the rapid increase in wheel loads and change in climatic conditions. Polymer modification can be considered as one of the solution to improvise the fatigue life, reduce the rutting & thermal cracking in the pavement. Asphalt, when blended or mixed with the polymer, forms a multiphase system, containing abundant asphaltenes which are not absorbed by the polymer. This increases the viscosity of the mix by the formation of a more internal complex structure.

1.3 Binder modification

Binder properties may be improved by different process and materials. Binder modification has been driven by the increase in traffic loads, new refining technologies, enhancement in polymer technology, the increasing need to recycle waste material such as plastic bag, plastic bottle, rubber and etc.

When we use the bitumen modifier, selected polymer/rubber or a blend of two or more modifier shall have the following properties:

- Compatible with bitumen,
- Resist degration at mixing temperature,
- Capable of being processed by conventional mixing and laying machinery,
- Produce required coating viscosity at application temperature and
- Maintain premium properties during storage, application and in-service.

The polymer and rubber modified bitumen shall be classified into four types as per IS:15462.2004 given below:

a) Type A PMP(P) – Platomeric thermoplastics based,
b) Type B PMB(E) – Elastomeric thermoplastics based,
c) Type C NRMB – Natural rubber and SBR latex based and
d) Type D CRMB – Crumb rubber/treated crumb rubber based.

Type A, Type B and Type C shall be further classified into three grades according to their penetration value and Type D shall be further classified into three grades according to their softening point values as given below:

Grades of Type A PMB(P) : PMB(P) 120, PMB(P) 70 and PMB(P) 40,
Grades of Type B PMB(E) : PMB(E) 120, PMB(E) 70 and PMB(E) 40,
Grades of Type C NRMB : NRMB 120, NRMB 70 and NRMB 40,
Grades of Type D CRMB : CRMB 50, CRMB 55 and CRMB 60.

Note: PMB(P) 120, PMB(E) 120 and NRMB 120 means that corresponding to this grade has penetration value between 90 to 150. PMB(P) 70, PMB(E) 70 and NRMB 70 means that corresponding to this grade has penetration value between 50 to 90. PMB(P) 40, PMB(E) 40 and NRMB 40 means that corresponding to this grade has penetration value between 30 to 50 and CRMB 50, CRMB 55, CRMB 60 means that corresponding to this grade has softening point value 50^0c, 55^0c and 60^0c minimum respectively.

1.3.1 Purpose of Bitumen modification

- To obtain softer blends at low temperature for reducing cracks.
- To increase the stability and strength of mixtures.
- To improve the asphalt cohesive strength in Pavements.
- To improve oxidation and resist aging.
- To reduce costs of pavement.

1.3.2 Advantages of Bitumen modification

- Lower susceptibility to daily & seasonal temperature variations.
- Higher resistance to deformation at elevated pavement temperature.

- Better age resistance properties, higher fatigue life of mixes.
- Better adhesion between aggregate & binder.
- Prevention of cracking & reflective cracking and

Overall improved performance in extreme climatic conditions & under heavy traffic condition

2. LIETRATURE REVIEW

Koudagani Venkatesh et al. [1] Bitumen is widely used in construction of flexible pavements due to its versatile properties like impermeability, Ductile, Binding; Bonding etc. plastic is used in almost all the industries including hospitals. The plastic waste generated from the hospitals has to be safely disposed to conserve environment. With increase in plastic content in bitumen after 7%, penetration and ductility values were decreases and resulting in increase the hardness and brittleness of bitumen and Optimum plastic content was found to be 5% in weight of bitumen content. Also the load carrying capacity was increased with increasing in plastic waste up to 7 percent by weight of bitumen.

Prof. Gopal C.Dhanjode et al [2] The plastic mixed with bitumen and aggregates is used for the better performance of the roads. The polymer coated on aggregates reduces the voids and moisture absorption. This results in the reduction of ruts and there is no pothole formation. The plastic pavement can withstand heavy traffic and are durable than flexible pavement. The use of plastic mix will reduce the bitumen content by 10% and increases the strength and performance of the road. This new technology is eco-friendly.

1. Plastic will increase the melting point of the bitumen.
2. This innovative technology not only strengthened the road construction but also increased the road life.

From the above research the remaining work will be design of pavement by using waste plastic. From the Prof. Gopal C.Dhanjode paper his concluded the 10% of bitumen replacing with Polythene gives the higher strength and this we are taking for this 10% replacement for pavement design and analysis with the help of IITPave software.

3. OBJECTIVE OF THE STUDY

The objective of the study undertaken is to design and evaluate the rutting and fatigue performance of flexible pavements for bitumen modified with plastic as per IRC provisions and mechanistic empirical software IITPAVE

4. METHODOLOGY

Lietrature review

Adopt the optimum plastic percentage for plastic road construction

Design and Analyis of Plastic roads by using IIT PAVE software

5. EXPERIMENTAL INVESTIGATION

5.1 General

The experiments carried out on the Soil Labaratory investigation. In this only CBR test we are findouted to design the pavement. The soil we are collected the surrounding of college.The California bearing ratio test is penetration test meant for the evaluation of subgrade strength of roads and pavements. The results mentioned below. The CBR value for the college soil is 10.5%.

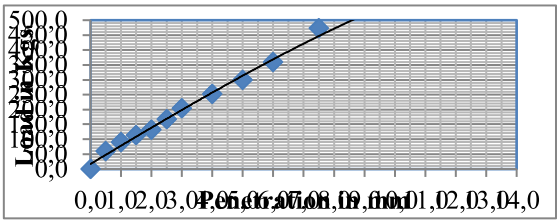

Fig. 1: Sample calculation graph of CBR.

6. DESIGN AND ANALYSIS OF PLASTIC ROAD

6.1 Design of Plastic Road (IRC 37: 2018 and IIT PAVE)

As discussed earlier the design of flexible pavements is done by using the guidelines of IRC 37: 2012 and applying the results to the IIT PAVE software.

6.1.1 Elastic Modulus and Poisson Ratio of Subgrade

The behaviour of the subgrade is essentially elastic under the transient traffic loading with negligible permanent deformation in a single pass. Resilient modulus is the measure of its elastic behaviour determined from recoverable deformation in the laboratory tests. The modulus is an important parameter for design and the performance of a pavement.

The relation between modulus and the effective CBR in IRC is given as (Annexure 1)

E (MPa) = 10 * CBR for CBR <= 5

= 17.6 * $(CBR)^{0.64}$ for CBR > 5

E= modulus of subgrade soil.

The poisons ratio of the subgrade is taken as **0.35** (From table 11.1 –IRC 37 2018)

6.1.2 Granular layer

Sub-base materials comprise natural sand, gravel, laterite, brick metal, crushed stone or combinations there of meeting the prescribed grading and physical requirements.

$E_{subbase} = E_{subgrade} * 0.2 * h^{0.45}$

h = Thickness of the DBM layer

Poisson's ratio of granular bases and sub-bases is recommended as 0.35.

6.1.3 Bituminous Layer

The surfacing consists of a wearing course or a binder course plus wearing course. The most commonly used wearing courses are surface dressing, open graded premix carpet, mix seal surfacing, semi-dense bituminous concrete and bituminous concrete. For binder course, MORTH specifies, it is desirable to use bituminous macadam (BM) for traffic upto to 5 msa and dense bituminous macadam (DBM) for traffic more than 5 msa.

The modulus for the bituminous material are obtained from the Table 9.2 in IRC 37: 2018

6.1.4 Failure Criteria and Strain Calculation

The flexible pavements has been modeled as a three layer structure and stresses and strains at critical locations have been computed using the linear elastic model. To give proper consideration to the aspects of performance, the following three types of pavement distress resulting from repeated (cyclic) application of traffic loads are considered

- Vertical compressive strain at the top of the sub-grade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.
- Horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.
- Pavement deformation within the bituminous layer.

6.2 IIT PAVE

IITPAVE software is used to calculate the Actual Horizontal Tensile Strain in

Bituminous layer and Actual Vertical Compressive Strain on sub-grade.

The actual strains are computed using various trial pavement thickness combinations. The tyre pressure used in the analysis is 0.56 MPa. Standard axle used is dual type and single tyre load of 20,000 N. The Poisson's ratio of bituminous layer is taken as 0.35. The E values and Poisson's ratio obtained from above are given as inputs to the software and strains are calculated.

- **Launching the software**

i.) From the Home screen user can manually give input through input window by clicking on 'Design New Pavement Section'. User can also give input through properly formatted input file by clicking on 'Edit Existing File' option then browsing and opening the input file.

ii.) Next an input window will come. All the inputs required have to be given through that input window.

- **Inputs to the Software**

i.) First, number of layers to be selected from drop down menu to fix up input boxes for different layer.

ii.) Next, Elastic modulus (E) values of the various layers in MPa, Poisson's ratio and thickness of the layers in mm excluding the subgrade thickness are to be provided.

iii.) Single wheel load and the tyre pressure are to be provided (tyre pressure of 0.56 MPa has been used for calibration of the fatigue equation and the same pressure can be used for stress analysis. Change of pressure even up to 0.80 MPa has a small effect upon stress values in lower layers.)

iv.) Then the number of points for stress computations is to be given through the drop down menu for Analysis points.

v.) Then corresponding to different points, the values of depth Z in mm and the corresponding value of radial distances from wheel centre (r) in mm are to be provided.

vi.) Provide whether analysis is for single wheel load or double wheel load by clicking 1 0r 2. 2 will be the most common case.

6.3 Calculations part

1. Compute the subgrade effective resilience modulas (M_{RS})

From Test results we got existence soil soaked CBR value of 10.5%.

Existing soil M_{RS} (Mpa) = $17.6 * (CBR)^{0.64}$

= $17.6 * (10.5)^{0.64}$ = 79.26 Mpa

2. Design Traffic

Data:

- Single lane
- In the college daily around 30 to 50 commercial vehicles are entering into the college and we are directly assuming design traffic is less than 5msa (Approximately taking 5msa).

3. Layer selection

Assuming

GSB = 150mm

WMM = 200mm

BASE / BINDER COURSE (DBM) = 50mm

SURFACE COURSE (BC) = 30mm

SUBGRADE = 500mm

4. PERMISSIBLE STRAIN:

a) Vertical strain (90% reliability)

$N_R = 1.41 \text{ X } 10^{-8} [1/ \varepsilon_v]^{4.5337}$

$5 \times 10^6 = 1.41 \times 10^{-8} \times [1/ \varepsilon_v]^{4.5337}$

$\varepsilon_v = 0.00061766$

b) Horizontal strain (90% reliability):

$N_F = 0.561 \text{ X } C \text{ X } 10^{-4} \text{ X } [1/ \varepsilon_t]^{3.89} \times [1/M_{RM}]^{0.854}$

$C = 10^M$ & $M = 4.84 [V_{be} / (V_{be} + V_a)]^{4.5337}$

Use, $V_{be} = 11.5$ & $V_a = 3.5$

M = 0.37 , C = 2.35

$M_{RM} = 1600$ Mpa (modified bitumen)

$5 \times 10^6 = 0.561 \text{ X } 2.35 \text{ X } 10^{-4} \text{ X } [1/ \varepsilon_t]^{3.89} \times [1/1600]^{0.854}$

$\varepsilon_t = 0.00037762$

5. Modulus for each layer:

sub-grade modulus = 79.26 Mpa

Modified bitumen with plastic layer modulus = 1600 Mpa

Granular layer modulus = M_{GRAN} = 0.2 $(h)^{0.45}$ x $M_{support}$ = 0.2 $(150+200)^{0.45}$ x 79.26 =221.26 Mpa

5.1 Working with IITPAVE

5.1.1 Plastic Road

Inputs:

Wheel load = 20000 N

Tyre Pressure = 0.56 MPa

Poisson's Ratio = 0.35

Radial distance = 155mm

Wheel set = 2

Strain Comparison:

1. Actual horizontal strain < = Permissible horizontal strain
2. Actual vertical strain < = Permissible vertical strain

Trail – 1:

SURFACE COURSE = 30mm

BASE / BINDER COURSE = 50mm

GSB = 150mm

WMM = 200mm

SUBGRADE = 500mm

sub-grade modulus = 79.26 Mpa

Modified bitumen with plastic layer modulus = 1600 Mpa

Granular layer modulus = M_{GRAN} = 0.2 $(h)^{0.45}$ x $M_{support}$

= 0.2 $(150+200)^{0.45}$ x 79.26 =221.26 Mpa

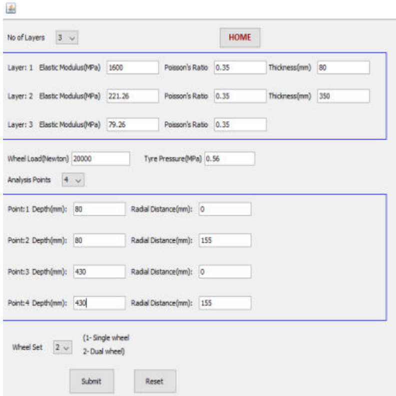

Fig. 2: Trail 1 input.

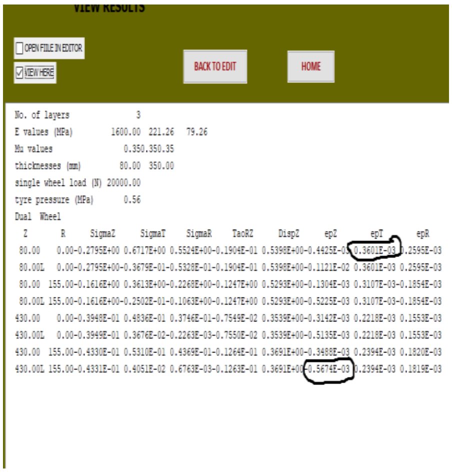

Fig. 3: Trail 1 output.

Strain Comparison:

Permissible horizontal strain = ε_t = 0.00037762

Actual horizontal strain = epT = 0.0003601

Permissible vertical strain = ε_V = 0.00061766

Actual vertical strain = epZ = 0.0005674

Here, 1. Actual horizontal strain < Permissible horizontal strain

2. Actual vertical strain < Permissible vertical strain

Hence Plastic Road is safe.

Trail – 2:

SURFACE COURSE = 30mm

BASE / BINDER COURSE = 50mm

GSB = 150mm

WMM = 180mm

SUBGRADE = 500mm

sub-grade modulus = 79.26 Mpa

Modified bitumen with plastic layer modulus = 1600 Mpa

Granular layer modulus = M_{GRAN} = 0.2 $(h)^{0.45}$ x $M_{support}$

= 0.2 $(150+180)^{0.45}$ x 79.26 =215.48 Mpa

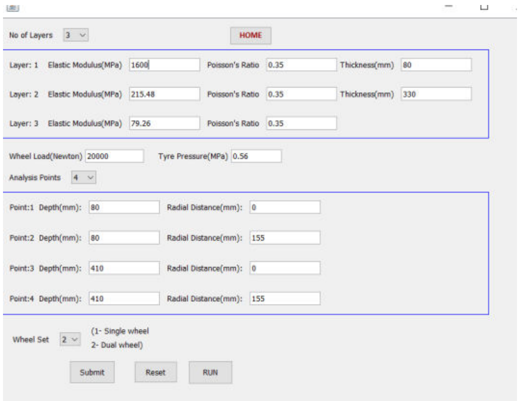

Fig. 4: Trail 2 input.

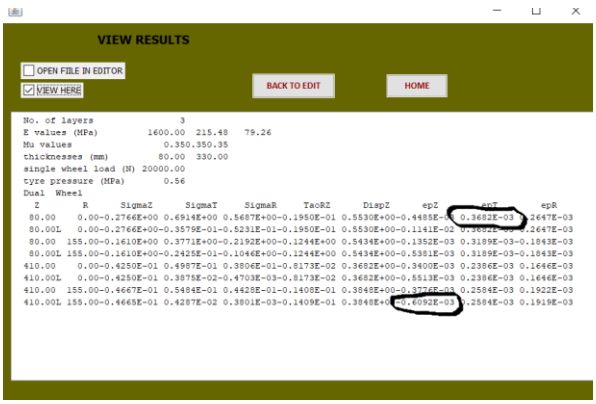

Fig. 5: Trail 2 output.

Strain Comparison:

Permissible horizontal strain = ε_t = 0.00037762

Actual horizontal strain = epT = 0.0003682

Permissible vertical strain = ε_V = 0.00061766

Actual vertical strain = epZ = 0.0006092

Here, 1. Actual horizontal strain < Permissible horizontal strain

2. Actual vertical strain < Permissible vertical strain

Hence Plastic Road is safe.

5.1.2 Bituminous Road

Inputs:

Wheel load = 20000 N

Tyre Pressure = 0.56 MPa

Poisson's Ratio = 0.35

Radial distance = 155mm

Wheel set = 2

Strain Comparison:

1. Actual horizontal strain < = Permissible horizontal strain

2. Actual vertical strain < = Permissible vertical strain

Trail – 1:

SURFACE COURSE = 30mm

BASE / BINDER COURSE = 50mm

GSB = 150mm

WMM = 200mm

SUBGRADE = 500mm

sub-grade modulus = 79.26 Mpa

BC and DBM for VG40 bitumen resilience modulus = 3000 Mpa

Granular layer modulus = M_{GRAN} = 0.2 $(h)^{0.45}$ x $M_{support}$

= 0.2 $(150+200)^{0.45}$ x 79.26 =221.26 Mpa

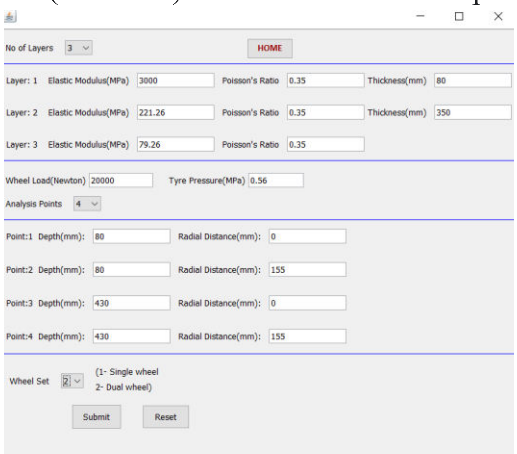

Fig. 6: Trail 1 input.

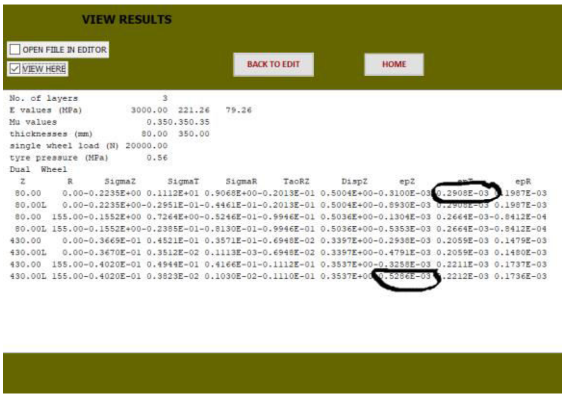

Fig. 7: Trail 1 output.

Strain Comparison:

Permissible horizontal strain = ε_t = 0.00037762

Actual horizontal strain = epT = 0.0002908

Permissible vertical strain = ε_V = 0.00061766

Actual vertical strain = epZ = 0.0005286

Here, 1. Actual horizontal strain < Permissible horizontal strain

2. Actual vertical strain < Permissible vertical strain

Hence Road is safe.

Trail – 2:

SURFACE COURSE = 30mm

BASE / BINDER COURSE = 50mm

GSB = 150mm

WMM = 160mm

SUBGRADE = 500mm

Sub-grade modulus = 79.26 Mpa

BC and DBM for VG40 bitumen resilience modulus = 3000 Mpa

Granular layer modulus = M_{GRAN} = 0.2 $(h)^{0.45}$ x $M_{support}$

= 0.2 $(150+160)^{0.45}$ x 79.26 =209.5 Mpa

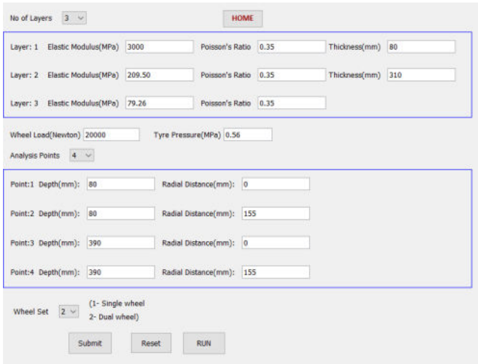

Fig. 8: Trail 2 input.

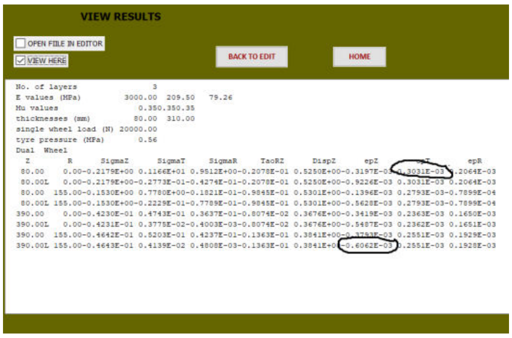

Fig. 9: Trail 2 output.

Strain Comparison:

Permissible horizontal strain = ε_t = 0.00037762

Actual horizontal strain = epT = 0.0003031

Permissible vertical strain = ε_V = 0.00061766

Actual vertical strain = epZ = 0.0006062

Here, 1. Actual horizontal strain < Permissible horizontal strain

2. Actual vertical strain < Permissible vertical strain

6. CONCLUSIONS

The study concludes that using plastic waste in road construction is a technically feasible and environmentally beneficial method for addressing both plastic pollution and infrastructure demands. Plastic-modified bituminous roads exhibit superior strength, higher resistance to water-induced damage, better flexibility, and increased lifespan compared to conventional roads.

From an environmental perspective, this approach provides a sustainable outlet for reusing non-biodegradable waste that would otherwise contribute to ecological degradation. Moreover, the use of plastics in road materials can lower construction costs, reduce the dependence on virgin bitumen, and encourage circular economy practices in the construction sector.

In summary, plastic road construction represents a significant innovation in sustainable civil engineering. While further research is needed on large-scale implementation, standardization, and long-term performance monitoring, the evidence supports its adoption as a viable and eco-friendly pavement solution for modern road networks

REFERENCES

[1] Koudagani Venkatesh, Ajay Swarup & Umank Mishra “Performance Analysis of Waste Plastic Modified Bitumen for Pavements”, RESEARCH REVIEW International Journal of Multidisciplinary 2021; 6(3):90-98 ISSN: 2455-3085 (Online).

[2] Prof. Gopal C.Dhanjode1 , Rohit A Kamble2 , Naina S. Bhagat3 , Irshad H. Baig4 , Diksha R. Khade5 Syed

Amjad Musain Khatib6 , Jayant A. Godbole7 , Chetan N. Raut8 , " Plastic Waste Bituminous Road Using Polythene" International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)- |Volume 10, Issue 5, May 2021|.

[3] IS.15462 : 2004, Polymer and rubber modified bitumen – Specification

[4] The United Republic of Tanzania_Laboratory Testing Manual (2000), Ministry of works.

[5] IRC 37-2018 , " design of flexible pavement