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Performance Evaluation of Road Pavement Green Concrete: An Application of Advance Decision-Making Approach before Life Cycle Assessment

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Abstract: Rigid pavement structures are one of the costly components of the infrastructure development process. It consumes a huge quantity of ingredients necessary for concrete development. Hence, a newly introduced concept of circular economy in combination with waste management was introduced to solve this problem. In this study, three waste products (rice husk ash (RHA), wood sawdust (WSD), and processes waste tea (PWT)) was utilized to develop the concrete for rigid pavement structures by replacing the sand, i.e., a filler material at different percentages. During the testing procedure of compressive (CS), tensile (TS), and flexural strength (FS) properties, RHA and WSD at 5% replacement were found to be a good replacement of sand to develop required concrete. This study will help in the production of eco-friendly rigid pavement structures and a pathway of life cycle assessment in the future.

Keywords: rigid pavement concrete; artificial neural networks (ANNs); green materials; eco-friendly

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1. Introduction

Climate change ambiguities coupled with the collapse of natural plus non-renewable resources are essential considerations that illuminate the prerequisite for inventive alterations that will advantage to a safer atmosphere prospect for everyone. Escalating the global economic disaster in conjunction with community constraints and challenges are crucial constraints that would be deemed in highly political and financial decision-making activities. These circumstances emphasize the consequence of the implementation of sustainable tactics, particularly for disciplines that are accountable for forming these customary conditions [1]. The transportation area is some of these areas as well as pavements, as part of this, are extremely related to the aforesaid aspects plus as well have a substantial impression on the greenhouse gas emissions, particularly carbon dioxide (CO_2), which is vastly linked to the environment transformation [2]. The hypothesis of pavement sustainability seeks the development of an eco-friendly, economic, and social structure. Even now, countless groups, firms, plus organizations have participated in complementary, inventive as well as primarily sustainable tactics for the intent of eco-friendly, economic, and social advancement [3,4]. A pavement is described as a comparatively durable crust built upon the native soil for the intent of assisting along with disseminating the wheel loads as well as delivering an ample wearing coat. Rigid pavements are invented of Portland cement concrete then may or may not need a base course among the pavement and the sub-grade. For of its firmness coupled with soaring tensile strength, a rigid pavement manages to disseminate the load around a comparatively broad section of soil, then a foremost part of the structural capability is provided via the slab itself [5]. Consequently, minimal alterations in sub-grade potency have a slight impact on the operational capability of the roadways. The rigid pavement is utilized for heavier loads than can be erected upon comparatively inadequate subgrade rigid pavement along with and devoid of base course are utilized in countless republics globally. The several layers of the rigid pavements structure have distinct strength as well as bend attributes, which become the layered structure tricky to evaluate in pavement manufacturing. In contrast, pavement foundation earth-materials, i.e., the sub-grade fine-grained soils, display nonlinear performance [6]. Globally, the pavement structure is comprised of almost 16.3 million kilometers [7].

The substances used as the fundamental part of the fabricated pavement distinguish the structural attributes as well as the value of the pavements. Furthermore, the exploited materials perform a key part in eco-friendly, economic, then community stability [8,9]. A portion of the sustainability tenets concerning pavements is the assortment of green materials at a minimal rate, concurrently bringing into appreciating the communal effects. Application of waste materials then byproducts is additionally a sustainable approach, while at the meantime landfilling use, stockpile sedimentation as well as waste dumping, are diminished [10]. Pavement sustainability is extremely centered upon a suitable assortment of materials. Typically, almost roadway materials are originated from non-renewable resources, destroying the atmosphere. Hence, the material source is a crucial attribute to eco-friendly influence mitigation. The central types of employed roadway materials are aggregate and asphalt as well as cementitious materials. Recognizing that the fabrication processes of these materials damage the atmosphere, sustainability leans to offer complimentary methods and more explanations for modification of the whole procedures. Such as recycling and deployment of waste materials [11,12]. A pertinent tradeoff may arise with the pavement quality then is not satisfactory, signifying that quality is an imperative matter that would not be miscalculated. Likewise, how a large amount of a material can be employed, especially a delicate matter. The value is occasionally restricted by the divergent standards, but then it falls on numerous parameters and different mathematical models are applied [13,14]. The foremost ample materials utilized for the manufacturing of pavements (rigid and asphalt pavements) are recognized as aggregate materials [11].

These proportion values demonstrate the general function of the aggregate materials contained by a pavement formation. Moreover, these materials are too frequently employed for lower pavement layers, for instance, base or subbase layers. As a substitute, aggregate materials are an essential part of the pavement structure. The reality that these are generally habitually obtained from non-renewable resources is a critically vital matter to be deemed. In addition, the transportation costs plus associated greenhouse gas emanations should too be factored in. Concerning materials, the main targets of pavement sustainability are the re-utilization of aggregates, primarily via several recycling approaches [15]. Further precisely, when current pavements have terrible destruction (e.g., deterioration, milling, defects, etc.), then subsequently, recycling is counted as a sustainable rehabilitation technique [16]. The literature illustrates that researchers utilized numerous kinds of waste and recycling materials as a substitute of aggregates for concrete pavements like Reclaimed asphalt pavement [17], steel furnace slag [18], recycled asphalt shingles [19], waste foundry sand and glass [20,21], crushed brick and powder [22,23], recycled concrete aggregates [24,25], construction and demolition waste aggregates [26], coal bottom ash [27], etc. Even different mathematical modeling techniques have been used to study the nonlinear behavior of variables [28–30]. Moreover, different artificial intelligence (AI) techniques like artificial neural networks (ANNs) have already been applied to analyze different properties of rigid pavement and the prediction of different output properties. Concrete pavements, else recognized as rigid pavements, are broadly utilized for certain purposes [31,32]. This ANNs technique has been applied to study the deflection data of rigid pavements [33] stress analysis [34] roughness [35] condition ranking of jointed concrete pavements [36] compressive strength of roller-compacted concrete pavements [37] and concrete pavement joint evaluations [38].

Certain of these are airports, ports, military facilities, parking lots as well as intense traffic roadways. Superior bearing capacity, endurance to constant vehicular load, plus enduring resilience are several of the very substantial mechanical attributes of concrete roadways. However, huge volumes of aggregates and cement are generally essential. Consequently, a prospective pavement design, efficient of assimilating sustainable materials besides accomplishing a persistent quality level, is a key intention of enhancing the sustainability of concrete pavements. Much research has been conducted by using different raw materials in different percentages in place of fine and coarse to check the mechanical properties of concrete involving compressive, tensile, as well as flexural strength. The researcher has used several raw materials; some of them are rice husk ash [39,40], palm oil fuel ash [39], bamboo fiber [41], bottom ash [42], ground granulated blast-furnace slag [43], tire rubber waste [44] furnace slag and welding slag [45] burnt clay pozzolana [46].

This study targets goals to produce eco-friendly green material concrete using different waste materials. For this purpose, two distinct kinds of concrete proportions were made to investigate the fresh and mechanical properties of concrete by the substitution of sand with waste materials (rice husk ash, wood sawdust, processed waste tea). Therefore, the strength characteristics of all specimens are evaluated through the mechanical investigation of each sort of specimen. After a huge laboratory investigation, the outcomes have been analyzed theoretically, experimentally, analytically, and statistically with the help of artificial neural networks (ANN). In the end, a conclusion is drawn to show a relationship among these waste material concrete after ANN enactment.

2. Materials and Methods

2.1. Basic Materials

The leading vital ingredient of mortar and concrete is recognized as an ordinary Portland cement, which is utilized for general activities of construction as a binder. Concrete is identified as the blend of binder, aggregates (inert material), and water. The water helps during the manufacturing, placing, and curing of concrete because the involvement of water produced adhesion among the ingredients. Generally, the total volume of concrete contains around 60–75% of aggregates, and the aggregates were allocated into two diverse sorts, the aggregate which passes through ASTM sieve #4 (pore size 4.76 mm) recognized as fine aggregate plus which retains on sieve #4 recognized as coarse aggregate.

In this study, the ordinary Portland cement of grade-53 was utilized as a binder material, according to ASTM Type-1 cement [47]. The key physical plus chemical characteristics of this cement are listed in Table 1 [48–52]. Further, the fine aggregate (sand) was obtained from "Chenab River", and the maximum size of this counted is 4.75 mm. A well-graded coarse aggregate obtained from "Sakhi Sarwar"utilized in this study comprises mixed sand (45%), and lime (55%) stone plus the nominal size of these aggregates is 20 mm. The physical properties of these ingredients are listed in Tables 1 and 2. Furthermore, Figures 1 and 2 shown the gradation curve of fine and coarse aggregates [53–59].

2.2. Waste Materials

A total of three waste materials, rice husk ash (RHA), wood sawdust (WSD), processes waste tea (PWT) utilized in this study for the development of sustainable concrete. All materials obtained were of (waste) form, and the materials were utilized as a fine aggregate. The wood sawdust was generated because of the sawing of woods, the processed waste tea generated later the preparation of tea, and the rice husk ash obtained after the burning of rice husk at an elevated temperature around 700 °C. The physical properties of these waste materials are shown in Table 2.

Table 1. Chemical characteristics of ordinary Portland cement.

Loss on Ignition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
3.78	20.17	5.04	2.94	66.42	1.71	3.09	0.79	0.55

Table 2. Basic and waste materials physical properties.

Property	Unit	Result	Standard
	Cement-Basic Binder		
Bulk density	kg/m^3	1440.00	ASTM C-188
Normal consistency	%	29.50	ASTM C-187
Fineness	%	94.54	ASTM C-184
Initial setting time	mints	139.00	ASTM C-191
Final setting time	mints	185.00	ASTM C-191
Soundness	mm	1.00	BS 196–3
	Fine Aggregates (sand)		
Fineness modulus	–	2.21	ASTM C-136
Bulk density	kg/m^3	1530.00	ASTM C-29
	Processed Waste Tea (PWT)		
Fineness modulus	–	3.55	ASTM C-136
Bulk density	kg/m^3	514	ASTM C-29
	Wood Sawdust (WSD)		
Fineness modulus	–	2.92	ASTM C-136
Bulk density	kg/m^3	677	ASTM C-29
	Rice Husk Ash (RHA)		
Fineness modulus	–	1.66	ASTM C-136
Bulk density	kg/m^3	152	ASTM C-29
	Coarse Aggregates		
Bulk density	kg/m^3	1500.00	ASTM C-29
Aggregate impact value	%	22.21	BS 812-3
Aggregate crushing value	%	28.11	BS 812-3
Los Angeles abrasion	%	30.00	ASTM C-131
Water absorption	%	2.43	ASTM C-127

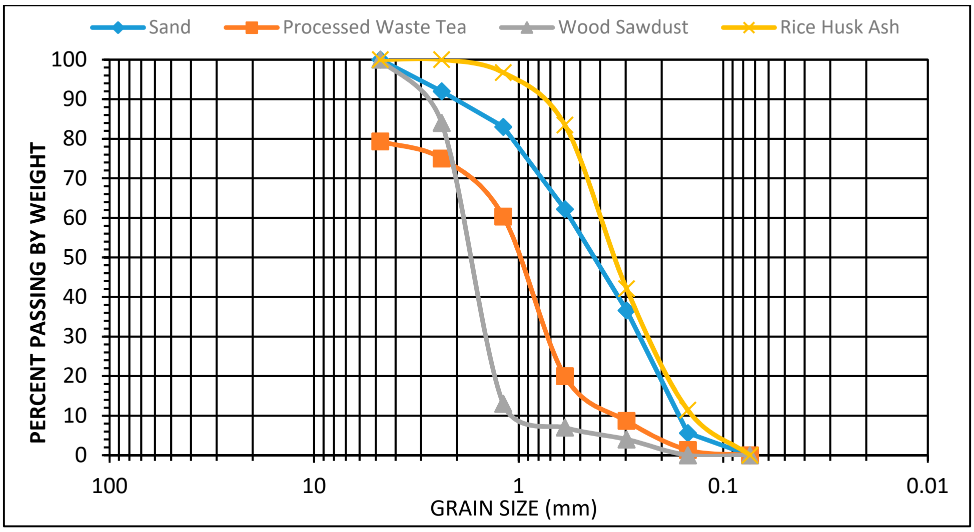


Figure 1. Fine aggregate sieve analysis.

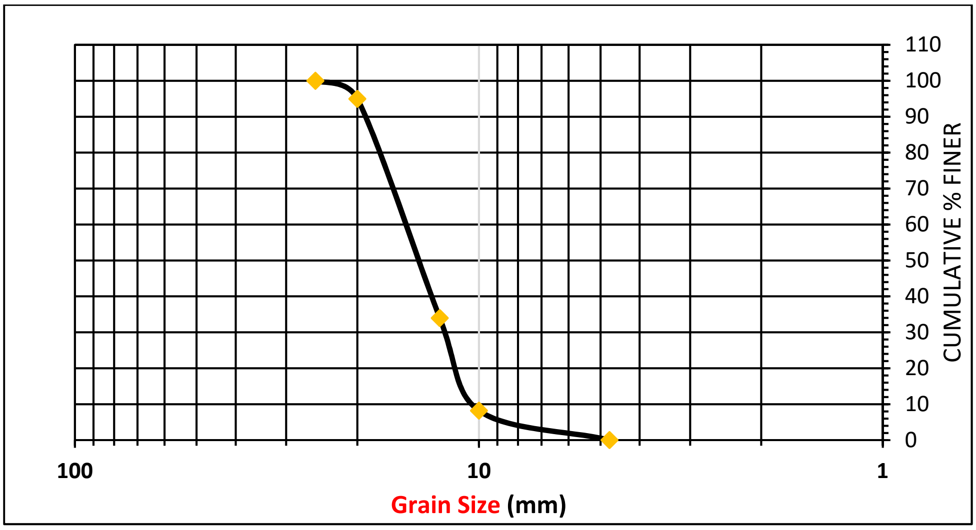


Figure 2. Coarse aggregate sieve analysis.

2.3. Mixing and Preparation of the Specimen

Typical concrete is produced by mixing cement, sand, water, and aggregate in a correct proposition. Usually, the mixing, transporting, compacting, placing, and curing of concrete plays a crucial role in terms of concrete durability and strength scenario. Meanwhile, the characteristics of concrete ingredients equally impact the properties of concrete. Good quality concrete should meet and fulfill the performance criterion equally in the plastic and hardened stage. In the plastic stage, concrete ought to be workable as well as exempt from segregation and bleeding. In the hardened stage, concrete ought to be strong, durable, and impermeable. In this work, the M15 (1:2:4) and M20 grade (1:1.5:3) concrete is prepared at a constant 0.55 w/c ratio, and the minimum and maximum curing periods are 7 and 28 days. The fine aggregates replaced with waste material at numerous percentages varies from 5%–15% by volume. At each percentage replacement total, 3 samples were prepared for each curing period plus the workability and fresh and hardened densities calculated for each one, respectively. For specimen preparation, ingredients mixing through hybrid concrete mixer and consistency as well as curing of specimens done according to ASTM C-192 and C-143 [60,61] and also, binder ingredients are verified according to ASTM C-150 [47]. The specimen size of the cylinder is 150 mm × 300 mm for compressive and tensile strength purposes. For flexural strength, 100 mm × 100 mm × 500 mm prism is prepared. Various properties of concrete, its compressive strength is the most important and is taken as a measure of its overall quality. The mix proportion and descriptive statistics of this sustainable concrete listed in Tables 3 and 4.

Table 3. Mix proportion of sustainable M15 and M20 grade concrete.

Mix ID	Grade	Details
P.C.C	M15	M15 grade Concrete (1:2:4)
WSD		Replacement of sand with 5%, 10%, 15% wood sawdust
RHA		Replacement of sand with 5%, 10%, 15% rice husk ash
PWT		Replacement of sand with 5%, 10%, 15% processes waste tea
P.C.C	M20	M20 grade concrete (1:1.5:3)
WSD		Replacement of sand with 5%, 10%, 15% wood saw dust
RHA		Replacement of sand with 5%, 10%, 15% rice husk ash
PWT		Replacement of sand with 5%, 10%, 15% processes waste tea

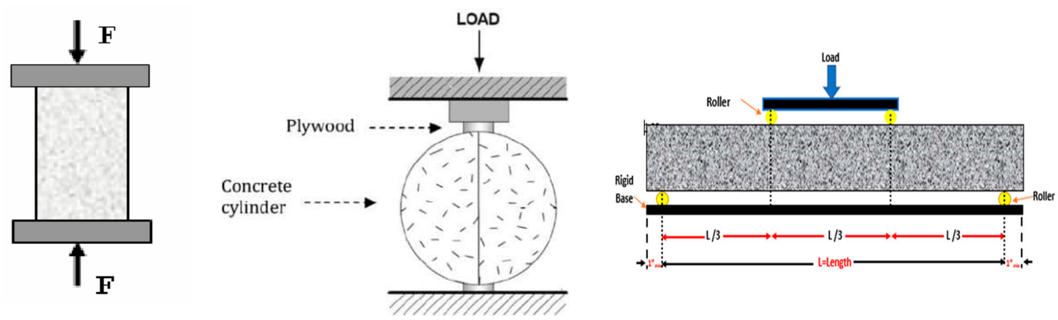
Table 4. Descriptive statistics data of eco-friendly rigid pavement green concrete.

Variable	Mean	St. Dev	Min.	Q1	Median	Q3	Max.
Replacement (%)	9	4.92	0	5	10	15	15
Curing (days)	–	–	7	7	–	28	28
Cement (kg/m^3)	354.5	37.66	317	317	354.5	392	392
Sand (kg/m^3)	599.25	35.68	546	573	607	633.5	674
Waste material (kg/m^3)	17.35	13.57	0	6.48	12.75	29.48	44.7
Aggregate (kg/m^3)	1290.5	30.6	1260	1260	1290.5	1321	1321
Water (kg/m^3)	198.5	23.6	175	175	198.5	222	222
Fresh density (kg/m^3)	2336.1	34.2	2253	2311.5	2330.5	2355.8	2421
Hardened density (kg/m^3)	2264.4	27.9	2208	2244.3	2264	2287.5	2330
Slump (mm)	67.4	17.32	35	53.25	66	78	113
Compressive strength (MPa)	12.52	6.348	2.27	7.396	11.944	16.817	27.78
Flexural strength (MPa)	2.907	1.357	0.643	1.775	2.85	3.928	6.14
Tensile strength (MPa)	1.6932	0.8903	0.1415	1.0303	1.6781	2.2597	3.51

Note: Q1: Quartile 1 and Q3: Quartile 3.

2.4. Specimen Testing Methods

To satisfy the mechanical properties criteria of concrete compression, flexure, and tension techniques are to be examined. The mechanical formation, according to ASTM C-39 [62], ASTM C-496 [63], ASTM C-78 [64], is followed to examine the mechanical properties of concrete at 7- and 28-days curing. Figure 3 shown the testing machine assembly formation used in work [65].



(**a**) (**b**) (**c**)

Figure 3. Strength testing machine mechanism (**a**) compressive, (**b**) tensile, (**c**) flexural tests.

2.5. Application of Artificial Neural Networks Model

Artificial neural networks (ANNs) are an advanced technique to apply for the prediction of certain parameters and are capable of handling multiple inputs and multiple outputs. For the prediction of mechanical properties of concrete, this technique was applied using JMP Pro, as shown in Figure 4.

The accuracy of prediction of dependent variables based on independent variables is tested through two parameters. These are the root-mean-squared error (RMSE), which is the difference between the actual and the predicted value and the difference of coefficient of determination (R^2) [43,66] as given below Equations (1) and (2).

$$\text{RMSE} = \sqrt{\left(\frac{1}{N}\sum_{n=1}^{N}(\text{actual} - \text{predicted})^2\right)} \quad (1)$$

$$R^2 = 1 - \frac{SSE}{SS_y} \quad (2)$$

where *SSE* is the sum of squared errors of prediction, *SSy* is total variation, *N* is number of observations and *n* is sample size. Usually, the performance of a model is compared by a coefficient of determination (R^2).

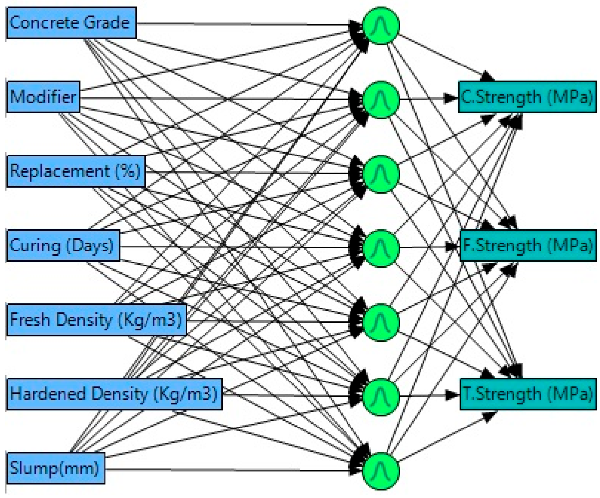


Figure 4. Artificial neural networks structure.

3. Results and Discussion

3.1. Mechanical Properties of Concrete

Mechanical properties of concrete materials, the compressive strength of green materials can be studied according to the performance of the compressive strength increases regarding the increase in density with time. Resistance against the tensile forces of concrete materials, the tensile strength of green materials can be studied according to the performance of the split tensile strength increases concerning an increase in density over time. However, with an increase in replacement percentages, it varies as the density of the materials also varies. An increase in density also indicates the densification of the packing characteristics of the concrete materials, which finally tends to increase the strength because of the reduction in the gaps between aggregates and binders as well as filler, which is in original sand. Hence, three materials ((rice husk ash (RHA), wood sawdust (WSD), and processes waste tea (PWT))) are utilized as replacement of sand at different percentages. Depending upon replacing materials, it also affects the density of the produced green concrete.

3.2. Relationship Analysis between Mechanical Properties

A balance among strength (compressive and tensile) properties of concrete can easily be comprehended through the ratio of these properties. Additionally, a medium level approach reveals that there is an imbalance in strength (compressive and tensile) behavior of this concrete. Figure 5 below briefly illustrates the behavior of each modifier against the percentage proportion.

Above the contour plot shows that the most balanced modifier as filler materials is sand, but only RHAC (rice husk ash concrete) is almost performing as that material as rice husk ash is performing as good filler. WT showed a poor balance ratio as compare to other modifiers. Even so, no modifier crosses the ratio of 12.5, which proves the imbalance fluctuations of these mechanical (compressive/tensile) properties. Similarly, another balance in strength is required between compressive strength to flexural strength ratio. The contour plot shows that the most balanced modifier as filler materials is sand, but only RHAC is almost performing like that material as filler, as shown in Figure 6. In this case, WSD exhibits good balance characteristics that balance ratio values range from 4–4.5. As compared to the above figure, a very fine balance situation can be seen in Figure 7. This means all modifiers illustrate the same balance behavior up to 4% substitution except

RHAC. The contour plot among the tensile/flexural strength ratio is shown in Figure 8 below.

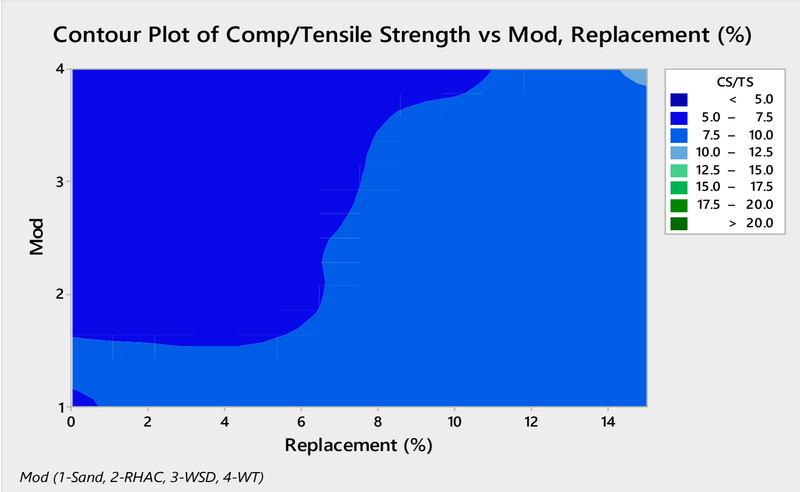


Figure 5. Contour plot of compressive/tensile strength (MPa) vs. mod, replacement (%).

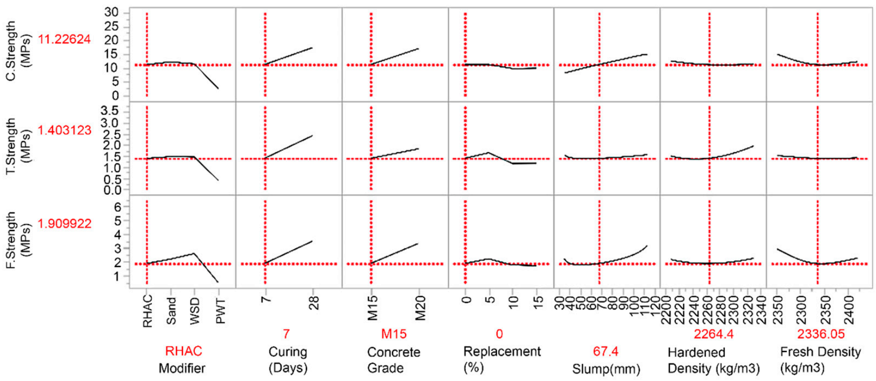


Figure 6. Prediction profile graph for the analysis of mechanical properties of green concrete.

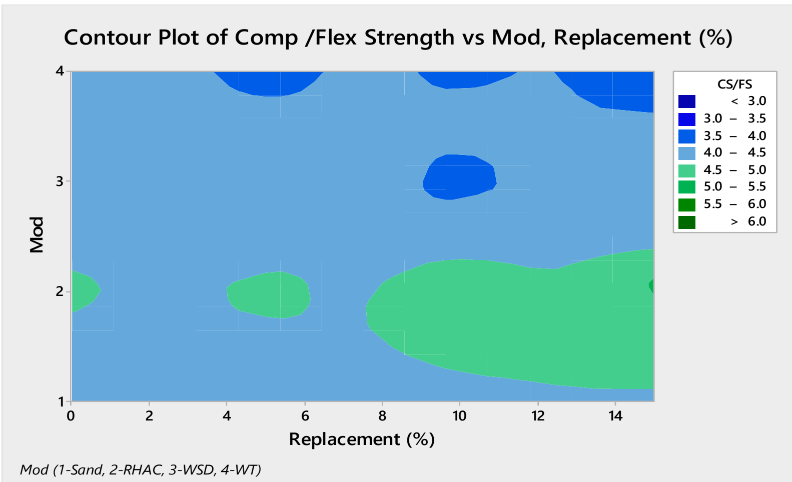


Figure 7. Contour plot of compressive/flexural strength (MPa) vs. mod, replacement (%).

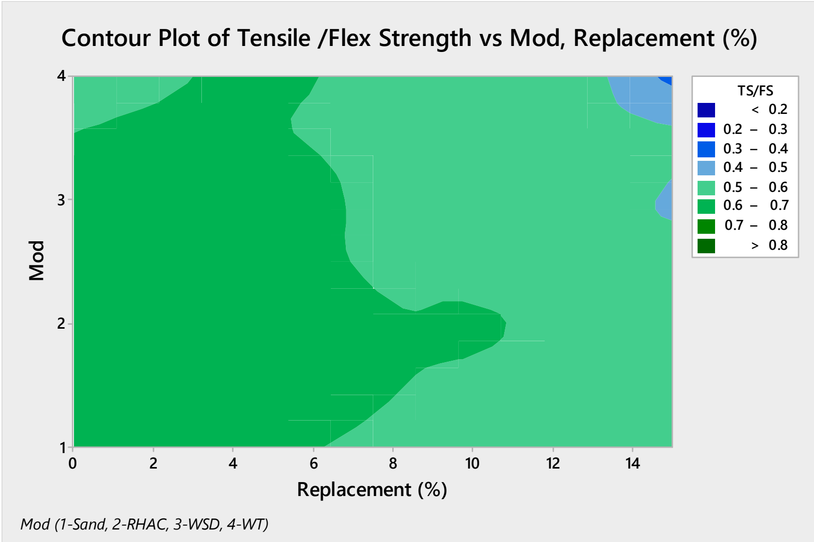


Figure 8. Contour plot of tensile/flexural strength (MPa) vs. mod, replacement (%).

Further, tensile to flexural balance is also discussed, and it is found out that is available up to 6% replacement of filler material, and after this, it reduces as shown in Figure 8. Afterward, the value of these strength properties fluctuates due to which imbalance situation occurs among these modifiers. Overall, the sand and RHAC counted to be balanced modifiers as parallel to remain modifiers.

3.3. ANNs Model Performance

Fundamentally, in the construction of an artificial neural network, deep-conceptual engineering was involved. This system contains a backpropagation neural system that entails a comprehensive learning rate and momentum etc., that incorporates a set of nodes, hidden layers, and their orders. For cross-validation, a K-folded mechanism was employed to predict and validate the prediction of the ANNs model. To identify the predictive power of the developed model, a relationship co-efficient like the co-efficient of determination (R^2) plus root-mean-square error (RMSE) was employed. Additionally, a classic fit would bring almost an R^2 of 1, as well as a poor fit about 0. The model parameters for the training and validation data of mechanical properties of eco-friendly rigid pavement green concrete listed in Table 5. As per rules of the K-folded mechanism, whole data split into five segments; so, 96 sample data for training plus 24 sample data for validation were selected out of 124 sample data. The R^2 value for each mechanical property that nears 1 demonstrates a higher level of accuracy of the developed model, i.e., for compressive strength, 0.96 for training, and 0.95 for validation; for tensile strength, 0.97 for training and validation and; for flexural strength 0.94 for training and validation. In contrast to more mechanical properties, tensile strength demonstrates the least RMSE, around 0.14 for training and 0.13 for validation, while compressive strength is also shown as a minimal RMSE almost 1.10 and 1.29 for training and validation data, respectively.

The training and validation model plots helpful for the judgment of the accuracy of the developed model. These plots separately illustrate the accuracy of each dependent variable in terms of training and validation data splits corresponding to the K-folded mechanism. All three properties can be seen in Figure 9 exemplify training and validation plots.

3.4. Prediction Profiler

The crucial purpose of a prediction profile to understand the impact of numerous independent variables on dependent variables. A prediction profile was generated after the enactment of the statistical ANNs model technique, which helpful for in-depth analysis of the generated model. Figure 6 demonstrates the behavior of variables that impact the mechanical properties of eco-friendly rigid pavement green concrete that developed through the utilization of waste materials.

Table 5. Model performance indicators for training and validation procedure.

Measures	Training	Validation
Compressive Strength (MPa)		
R^2	0.969402	0.9575216
RMSE	1.1083706	1.2900781
Sum freq	96	24
Tensile Strength (MPa)		
R^2	0.9746607	0.9772819
RMSE	0.1412995	0.13299
Sum freq	96	24
Flexural Strength (MPa)		
R^2	0.9493726	0.9459538
RMSE	0.2944877	0.3492705
Sum freq	96	24

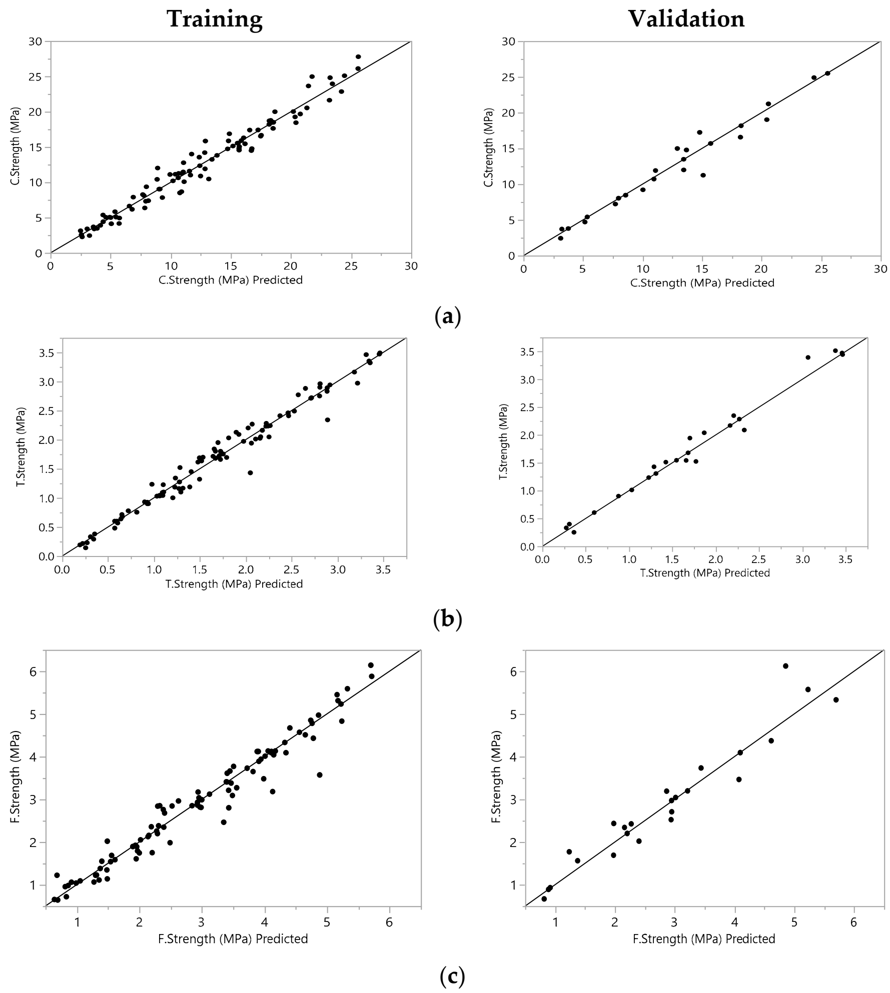


Figure 9. Training and validation plots for (**a**) compressiv strength, (**b**) tensile strength, (**c**) flexural strength.

From the left, the first column recognized as "modifier" demonstrate the fluctuations of mechanical properties of concrete against the substitution of each waste material. Compressive and tensile strength shows a similar trend, plus the values of these properties decreased after the substitution of sand with waste tea. Meanwhile, the highest value of flexural strength was achieved after the addition of wood sawdust as compare to other waste materials. The second and third column of this profile briefly demonstrates the positive impact of concrete curing and grade on the mechanical aspects of this green concrete. Moreover, the fourth column, recognized as "replacement," reveals that at 10% and 15% replacement, the value of compressive strength drops, in the case of tensile and flexural strength at 5%, substitution value rises, then further substitution declines the values. The fifth column demonstrates that as the slump value rises, the mechanical properties rise equally except in the case of tensile strength, which does not rise too much. The last two columns illustrated the similar tends that briefly discuss over as well as the indirect relationship that can be seen among compressive strength and density values.

3.5. Interaction Profiler

To briefly investigate the performance of each target variable concerning all other parameters, the interaction profiles are suggested as the best graphic tool later than the explanation of prediction profiles. For deep investigations of each target variable against the overall parameters, the trend behavior showed below in Figures 10–12.

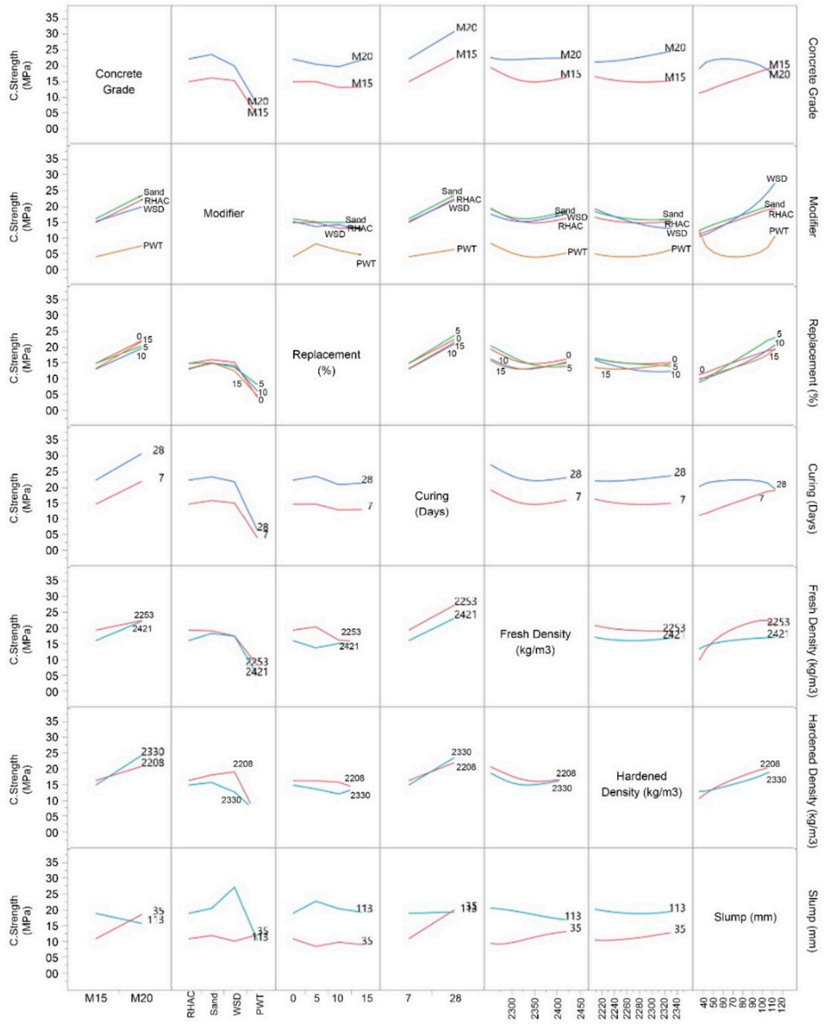


Figure 10. Compressive strength interaction profile.

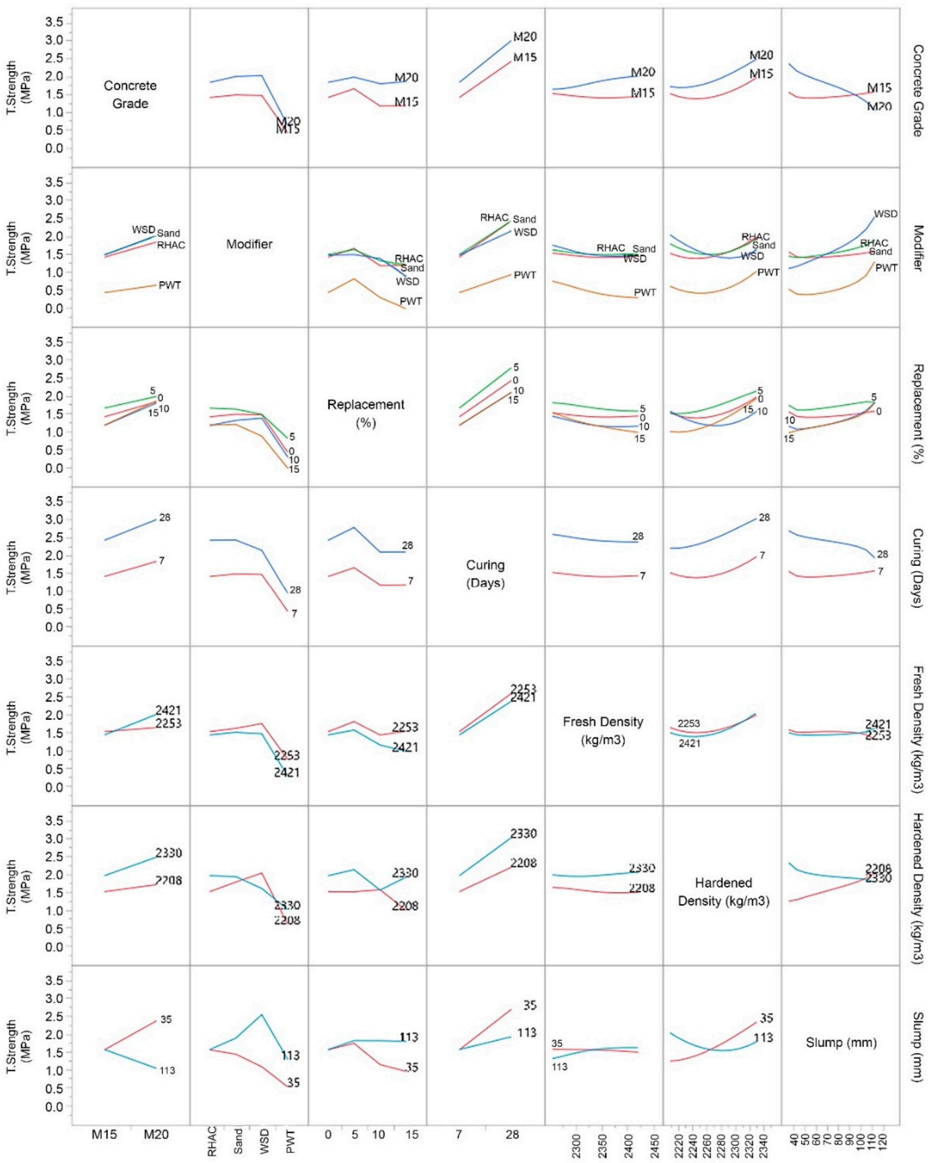


Figure 11. Tensile strength interaction profile.

Figure 10 demonstrates the detailed trend performance of compressive strength against each independent variable. The first box of the first row illustrates the behavior of compressive strength against concrete grade for the remaining six variables. The second box of the same row displays the strength of each grade concrete regarding fine aggregates; for both grades, waste tea has less compressive strength as a contrast to others. Further, the third box showed the compressive strength at each percentage substitution of waste materials for both grade concrete. M20 grade concrete strength rises at 15% substitution of sand, while M15 grade concrete strength is reduced at the same percentage substitution. The very next fourth box elaborates on the positive effect of both grade concrete compressive strength. Moreover, the fifth and sixth box, prove the direct relationship of fresh and hardened density concerning compressive strength only for M20 grade concrete, indirect relationship for M15 grade concrete. The last box of the first row illustrates the slump effect for compressive strength about both concrete grades. Afterward, the first box of the second row displays the performance of each modifier for compressive strength development to concrete grade. The third and fourth boxes exhibit the modifier behavior at each curing period and percentage substitution; the waste tea has not well compressive strength as compared to other modifier strength values. Similarly, the remaining last three boxes of the second row shown that the waste tea modifier did not successfully achieve the desired strength values about each variable, like densities and slump, etc.; as the slump value rises, the WSD compressive strength rises simultaneously.

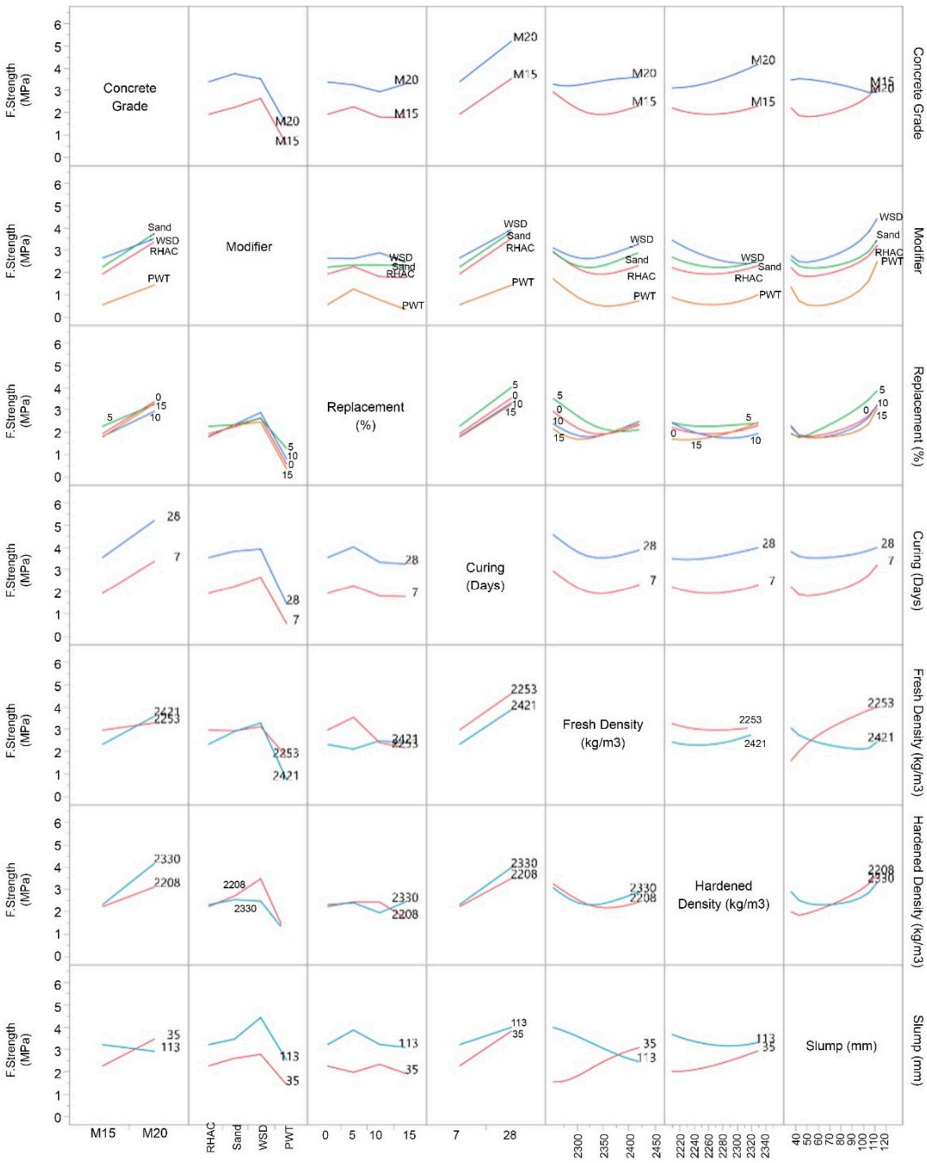


Figure 12. Flexure strength interaction profile.

Flexural strength trends can be observed in Figure 12. Wood sawdust has shown an impact on flexural strength profile showing a higher strength at 5% replacement only. Hence, a potential impact was observed as per utilization of raw materials.

3.6. Variable Importance Analysis

After a brief explanation of the above profiles, the next step to visualize the importance and effect of each independent variable that helpful for the successful development of eco-friendly rigid pavement green concrete. Table 6 shows the overall effect of each parameter. Modifier type and curing period identified as crucial parameters. While hardened and fresh density has the least effective parameter in the overall analysis. Moreover, in the case of compressive strength, modifier, curing period, and slump parameters have been recognized as the three most valuable contributors. In the case of tensile and flexural strength, modifier, curing period, and concrete grade identified as a leading contributors to these properties. Therefore, in the development of compressive and flexural strength. Fresh and hardened density is seen as the least leading effective contributor.

Table 6. Impact and variable importance of all parameters.

Parameter	Main Effect	Total Effect	Profile
Overall			
Modifier	0.487	0.563	
Curing (days)	0.195	0.24	
Concrete grade	0.087	0.136	
Slump (mm)	0.029	0.11	
Replacement (%)	0.037	0.073	
Hardened density (kg/m^3)	0.035	0.06	
Fresh density (kg/m^3)	0.017	0.035	
Compressive Strength (MPa)			
Modifier	0.544	0.664	
Curing (days)	0.15	0.198	
Slump (mm)	0.03	0.148	
Concrete grade	0.088	0.132	
Replacement (%)	0.017	0.041	
Hardened density (kg/m^3)	0.014	0.03	
Fresh density (kg/m^3)	0.013	0.024	
Tensile Strength (MPa)			
Modifier	0.457	0.501	
Curing (days)	0.212	0.252	
Concrete grade	0.083	0.125	
Hardened density (kg/m^3)	0.066	0.101	
Replacement (%)	0.057	0.096	
Slump (mm)	0.03	0.086	
Fresh density (kg/m^3)	0.012	0.019	
Flexural Strength (MPa)			
Modifier	0.46	0.524	
Curing (days)	0.224	0.27	
Concrete grade	0.091	0.15	
Slump (mm)	0.026	0.096	
Replacement (%)	0.036	0.081	
Fresh density (kg/m^3)	0.026	0.063	
Hardened density (kg/m^3)	0.025	0.049	

4. Conclusions

The study successfully utilized all waste material to produce sustainable green concrete for rigid pavements. On both ratios of concrete, the fine aggregates have been substituted with waste materials. Due to the huge amount of data, the ANNs technique deeply and extensively evaluates all the data, then the outcomes of the model exhibited the achievements of all study targets. Meanwhile, rice husk ash has achieved the highest strength as contrasted to other waste material concretes, but not greater than control samples in both grade concrete scenarios. Hence, processed waste tea outcomes demonstrated fewer strength characteristics for all kinds of mechanical testing of specimens. Due to its negligible adhesion and high moisture content absorption attributes, a slight bond has been formed among tea waste and concrete ingredients. Further, the model reveals all the aspects of this examination and the performance of this study model review through R-squared and root-mean-square error values. RHA and WSD concrete displayed a well mechanical property, plus it is most suitable for rigid pavements as a contrast to PTW. Following are the detailed analysis of the study as follows:

- Green concrete pavement was developed utilizing three waste products (rice husk ash (RHA), wood sawdust (WSD), and processes waste tea (PWT)) to develop the concrete for rigid pavement structures by replacing the sand, i.e., a filler material at different percentages (5%, 10% and 15%) using two mix design formations of M15 grade (ratio 1:2:4) and M20 grade (ratio 1:1.5:3);
- Performance analysis of developed green concrete is usually evaluated based on the performance of mechanical properties (i.e., compressive strength, tensile strength, and flexural strength;
- Compressive strength of developed green concrete also has been analyzed for two grades of concrete mix design formations of M15 grade (ratio 1:2:4) and M20 grade (ratio 1:1.5:3), and higher strength was observed for M20 grade. Furthermore, RHAC and WSD can be a good replacement at 5% replacement of sand if the grain size is kept at a similar level;
- Tensile strength of developed green concrete was analyzed for similar M15 grade (ratio 1:2:4) and M20 grade (ratio 1:1.5:3), and higher split tensile strength was observed for M20 grade using RHAC and WSD, which can be a good replacement at 5% replacement of sand if the grain size is kept at a similar level;
- Flexural strength of developed green concrete has additionally been analyzed for similar M15 grade (ratio 1:2:4) and M20 grade (ratio 1:1.5:3), and higher flexural strength was observed for M20 grade using WSD, which can be a good replacement at 5% replacement of sand if the grain size is kept at a similar level;
- As an advanced decision-making technique, artificial neural networks (ANNs) were utilized to predict the three mechanical properties that help in not only prediction but also develop a prediction profile to study the behavior of developed green concrete in one form of graphs.

This study will help to utilize waste materials as a replacement of sand for the formation of road pavement concrete and will also help in studying concepts of circular economy and life cycle assessment for future infrastructure development and management.

5. Limitations of the Study

In this research, green waste materials were used to produce rigid pavement concrete, which is an eco-friendly application to produce suitable pavement layer materials. A change in material mixing can lead to eco-friendly concrete pavement for economical construction. This study was conducted as the initial stage of research before the life cycle assessment of the rigid pavement concrete structures. Future examinations of sections of LCA will be conducted after further studies.

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