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Evaluation of Highway Construction Materials Performance: A Comparative Study of Asphalt Concrete and Portland Cement Concrete

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Abstract

Highway construction materials play a critical role in determining the durability, strength, and long-term performance of road infrastructure. The selection of appropriate materials impacts not only the structural integrity of highways but also their maintenance costs and lifespan. However, there is often a challenge in determining which material offers optimal performance under varying environmental and load conditions. This study evaluates the performance of two widely used highway construction materials - Asphalt Concrete (AC) and Portland Cement Concrete (PCC), by analyzing their strength characteristics through data visualization and regression analysis. The research employs a sample comprising 500 data points, where strength scores indicating material performance were recorded for highways constructed with either AC or PCC. Standard data preprocessing techniques, including outlier detection and normalization, were applied to ensure data integrity. Simple Linear Regression (SLR) analysis was utilized to determine the statistical significance of material selection on highway performance. Results indicate that PCC consistently outperforms AC in terms of strength, with an average strength score of 85.6 compared to 73.2 for AC. The regression model yielded an R^2 value of 0.78, indicating a strong predictive relationship between material type and strength. The F-statistic of 112.45 ($p < 0.001$) confirms the statistical significance of material choice, reinforcing PCC's superior load-bearing capacity. The heatmap and regression plots further highlight the correlation, while the scatter plot visually demonstrates the spread of strength scores, with PCC clustering at higher values. The study concludes that PCC is the preferred material for high-load highways due to its superior strength and durability, while AC remains viable for flexible pavement applications where rapid installation and cost-effectiveness are key factors. It is recommended that future studies incorporate additional parameter such as material aging effects to refine the performance evaluation model. These findings provide valuable insights for civil engineers and policymakers in optimizing material selection for sustainable and high-performance highway infrastructure. In future improvement of this work, we suggest the inclusion of performance indicators, such as durability under varying environmental conditions, cost analysis, or service life predictions for a more robust model.

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1.0 Introduction

Highways play a crucial role in transportation infrastructure, serving as key conduits for economic activities, trade, and mobility. The effectiveness of a highway depends significantly on the quality of construction materials (Jamshidi et al., 2019) and the efficiency of design performance. Construction Materials and Design Performances. Construction materials refer to the various substances used in the building of highways (Abdel *et al*., 2008**)**, including asphalt, concrete, aggregates, steel, and stabilizing agents. These materials are selected based on their strength, durability, flexibility, and resistance to environmental factors such as temperature changes, moisture, and heavy traffic loads. Asphalt is commonly used for flexible pavements due to its ability to withstand repeated loading and expansion, while concrete is preferred for rigid pavements because of its high compressive strength and longevity. The quality of these materials directly impacts the structural integrity and lifespan of highways, making their evaluation essential in construction projects. Design performance pertains to the effectiveness of highway structures in meeting functional and durability requirements. This includes factors such as pavement thickness (Dahalan *et al*., 2024), load distribution, drainage efficiency, and resistance to wear and tear. A well-designed highway should accommodate varying traffic volumes, minimize surface distress, and ensure smooth driving conditions (Mehrjardi *et al.*, 2020). Modern design approaches integrate engineering simulations and predictive models to optimize highway performance under real-world conditions. Proper evaluation of both materials and design ensures that highways remain safe, cost-effective, and sustainable throughout their service life. Various materials, such as asphalt, concrete, and aggregates, are used in highway construction, each possessing unique properties that influence the durability, strength, and overall longevity of road structures. Proper evaluation of these materials ensures compliance with engineering standards and environmental requirements, thereby enhancing road safety and sustainability. The selection of construction materials is influenced by several factors, including climatic conditions, traffic load, and soil characteristics (Radzi *et al*., 2023). Asphalt, for instance, is widely used due to its flexibility and ability to withstand varying temperatures, while concrete roads offer superior strength and durability in high-traffic areas. Aggregates, including crushed stones and gravel, form the structural foundation of highways, impacting load-bearing capacity and resistance to wear and tear. Evaluating these materials involves laboratory and field tests to determine their mechanical and chemical properties, ensuring optimal performance under different environmental and operational conditions. Apart from material selection, highway design plays a fundamental role in determining the lifespan and functionality of a road. Modern highway designs incorporate advanced engineering principles that account for load distribution, drainage systems, and pavement thickness. Poor design choices can lead to premature deterioration, manifesting in issues such as rutting, cracking, and potholes. Therefore, highway engineers employ simulation models and real-world testing to optimize design parameters, ensuring that highways can withstand the expected traffic volume and environmental stressors. Performance evaluation of highways (Ebrahim *et al*., 2016**)** is an ongoing process that involves monitoring structural integrity, surface conditions, and traffic flow efficiency. Technologies such as ground-penetrating radar, pavement condition surveys, and intelligent transportation systems help assess road performance over time. Regular maintenance strategies (Njeru *et al.*, 2022), including resurfacing, sealing cracks, and improving drainage systems, are essential to extending the lifespan of highways. Performance evaluation also includes cost-benefit analysis to determine the economic feasibility of construction and rehabilitation projects. Sustainability has become a major consideration in highway construction, driving the adoption of environmentally friendly materials and innovative construction techniques. The use of recycled asphalt, warm-mix asphalt, and geopolymer concrete reduces the environmental impact of road projects while maintaining structural integrity. Additionally, green infrastructure approaches, such as permeable pavements and bioengineered drainage solutions, contribute to sustainable highway designs by minimizing water runoff and enhancing ecological balance (Brochner *et al.*, 2019). Evaluating these emerging materials and methods ensures that modern highways meet both economic and environmental objectives. The objective of this research is to carry out the evaluation of highway construction materials performance. The aim would be to focus on a comparative study of Asphalt Concrete and Portland Cement Concrete.

1.1 Research Problem

One of the primary challenges in highway construction is ensuring the long-term durability and performance of roads despite varying environmental conditions, increasing traffic loads, and material limitations. Many highways experience premature deterioration due to poor material selection, suboptimal design practices, and inadequate maintenance strategies. Issues such as cracking, potholes, rutting, and surface degradation not only lead to high repair costs but also compromise road safety and efficiency. Traditional evaluation methods often fail to provide accurate predictions of highway lifespan and performance, making it difficult to implement proactive maintenance and cost-effective construction techniques. Additionally, the lack of advanced data-driven approaches in highway evaluation presents a significant limitation. While large amounts of data are collected during material testing, traffic monitoring, and structural assessments, they are often underutilized due to insufficient analytical methods. The absence of integrated data visualization and predictive modeling tools, such as regression analysis, hinders the ability to identify patterns and anticipate potential failures. Without leveraging modern statistical and computational techniques, engineers struggle to optimize construction materials and design parameters effectively. This research aims to address these gaps by integrating advanced analytical methods to enhance the evaluation of highway construction materials and design performance, leading to more sustainable and resilient infrastructure.

2.0 Literature Background

Highway construction and design performance have been widely studied to ensure the durability, safety, and efficiency of road infrastructure. Researchers have explored various aspects, including material selection, structural design, and the use of data-driven approaches to optimize road performance. By examining past studies, this section provides an overview of the evaluation of construction materials, the impact of design parameters, and the role of data analytics in improving highway engineering.

2.1 Evaluation of Highway Construction Materials

Highway construction materials play a critical role in ensuring road durability, safety, and performance. Various studies have examined the mechanical, chemical, and environmental properties of materials (Jiang *et al.*, 2021) such as asphalt, concrete, and aggregates to determine their suitability for highway construction. Research has shown that modified asphalt binders, such as polymer-modified bitumen, significantly enhance pavement resistance to rutting, cracking, and temperature variations (Shrestha *et al.*, 2012). Additionally, concrete highways incorporating supplementary cementitious materials, such as fly ash, silica fume, and slag, have been found to improve compressive strength, reduce permeability, and enhance durability. Evaluating these materials through laboratory testing and field performance analysis ensures that roads meet engineering and environmental standards. Furthermore, recent studies have explored the use of sustainable and recycled materials in highway construction to reduce costs and environmental impact. The incorporation of recycled asphalt pavement (RAP), warm-mix asphalt (WMA), and geopolymer concrete has been shown to provide comparable, if not superior, performance to conventional materials while reducing carbon emissions. The durability and mechanical performance of these materials depend on factors such as mixing techniques, aggregate gradation, and binder composition. Comprehensive evaluation methods, including performance grading (Fathi *et al*., 2022), fatigue testing, and rutting resistance analysis, are essential for selecting the best materials for highway projects.

2.2 Impact of Design Parameters on Highway Performance

Highway design parameters significantly influence road functionality, structural integrity, and long-term maintenance requirements. Several studies highlight that inadequate pavement thickness, poor drainage systems, and improper load distribution lead to early deterioration, resulting in frequent maintenance and repair costs. Research has shown that pavement thickness must be designed based on expected traffic loads, environmental factors, and soil conditions to ensure long-term performance. Advanced structural design models incorporate factors such as dynamic traffic loading, thermal expansion effects, and subgrade strength to optimize pavement life and reduce distress. There are prediction models like Artificial Neural Networks such as demonstrated by (Ekong *et al*., 2022) that can help increase impact of design parameters. Proper drainage design is also a key factor, as water accumulation weakens the pavement structure, leading to cracking and potholes. Modern highway design approaches utilize engineering simulations and machine learning techniques to predict potential failures and improve pavement resilience. Studies have demonstrated that integrating finite element modeling (FEM) and pavement performance prediction models like the kind of model used by (Ekong *et al*., 2023) can help engineers develop optimized designs that minimize cracking, rutting, and surface distress. Additionally, sustainable design approaches, such as permeable pavements and bioengineered drainage solutions, have gained traction in highway engineering. These innovations improve road durability while addressing environmental concerns such as stormwater management and heat island effects. Research in this field continues to evolve, incorporating smart road technologies and adaptive pavement systems for enhanced highway performance.

2.3 Application of Data Analytics in Highway Engineering

The integration of data analytics in highway engineering has transformed how road materials and design performances are evaluated. Studies have shown that data visualization techniques (Uwah & Edet, 2024), including Geographic Information Systems (GIS), remote sensing, and digital mapping, help engineers monitor road conditions more effectively. Visualization tools (Edet et al., 2024) enable stakeholders to assess pavement distress, identify high-risk areas

(Ebong et al., 2024), and prioritize maintenance efforts based on real-time data. The use of sensors and Internet of Things (IoT) devices has further enhanced data collection (Edet et al., 2024), allowing engineers to track traffic patterns, material performance, and environmental impacts dynamically (Inyang & Umoren, 2023). Such data-driven approaches improve decision-making and enable the early detection of road failures. Regression analysis has also been widely used in highway engineering to predict pavement deterioration, optimize maintenance strategies, and assess material effectiveness. Multiple regression models allow engineers to analyze the impact of various factors such as traffic volume, temperature fluctuations, and material composition on pavement lifespan. Research has demonstrated that machine learning algorithms, such as random forests and neural networks, can enhance regression models by providing more accurate and dynamic predictions. Additionally, cost-benefit analysis using predictive modeling helps engineers evaluate different construction materials and design alternatives, ensuring that highway projects are both financially and structurally efficient. The growing use of data analytics in highway evaluation is leading to more resilient and cost-effective road infrastructure.

Table 1: Properties and Applications of Highway Construction Materials

Material	Description	Area of Strength	Weaknesses	Typical Applications
Asphalt Concrete (Bituminous Mix)	A mixture of bitumen (binder) and aggregates used for flexible pavements.	High flexibility, good skid resistance, quick construction.	Susceptible to temperature changes, requires periodic maintenance.	Road surfacing, highways, airport runways.
Portland Cement Concrete (PCC)	A composite material made of cement, water, sand, and coarse aggregates.	High compressive strength, long lifespan, low maintenance.	Brittle under tensile stress, prone to cracking without reinforcement.	Rigid pavements, bridges, tunnels, heavy-load roads.
Crushed Stone Aggregate	Processed stone used as a base or sub-base material in road construction.	Excellent load distribution, good drainage properties.	Requires proper compaction, may shift under high loads.	Base course, sub-base for roads, drainage layers.
Steel Reinforcement (Rebar)	Steel bars embedded in concrete to improve tensile strength.	High tensile strength, prevents concrete cracking.	Susceptible to corrosion if not protected.	Reinforced concrete pavements, bridges, tunnels.
Geotextiles & Geogrids	Synthetic fabrics used for soil stabilization and reinforcement.	Enhances subgrade stability, improves drainage, prevents soil erosion.	Can degrade under UV exposure if not properly installed.	Roadbed reinforcement, retaining walls, erosion control.

Lime Stabilized Soil	Soil mixed with lime to improve strength and durability.	Enhances soil bearing capacity, reduces shrink-swell potential.	Not suitable for highly organic or sandy soils.	Subgrade stabilization, embankments, low-traffic roads.
Fly Ash	A by-product of coal combustion used as a partial replacement for cement.	Improves concrete workability, reduces permeability, enhances durability.	Requires proper curing conditions, setting time may be longer.	Concrete roads, pavements, soil stabilization.
Recycled Asphalt Pavement (RAP)	Milled or reclaimed asphalt reused in new pavement construction.	Environmentally friendly, cost-effective, retains good performance characteristics.	Performance depends on mix design, potential for inconsistent properties.	Asphalt resurfacing, patch repairs, secondary roads.
Warm Mix Asphalt (WMA)	Asphalt mixture produced at lower temperatures than conventional hot mix asphalt.	Reduces fuel consumption, lowers emissions, improves workability.	Requires specialized additives, may have higher initial cost.	Sustainable highway construction, urban roads.
Polymer Modified Asphalt (PMA)	Asphalt binder modified with polymers to improve performance.	Increased resistance to rutting and cracking, enhanced elasticity.	More expensive than conventional asphalt.	High-traffic roads, extreme climate regions.
High-Performance Concrete (HPC)	Concrete with superior durability, strength, and resistance to environmental factors.	High resistance to freeze-thaw cycles, reduced permeability.	Higher material and production costs.	Bridges, tunnels, long-span pavements.

The strength of highway construction materials is determined through a series of standardized laboratory and field tests that assess their mechanical, durability, and load-bearing properties. In civil engineering, compressive strength is evaluated using the uniaxial compression test for concrete and stabilized soils, where cylindrical or cubical specimens are subjected to increasing axial loads until failure, following ASTM C39 standards. Tensile strength is assessed through the indirect tensile strength (ITS) test for asphalt mixtures and the splitting tensile test for concrete (ASTM C496). For flexible pavements, Marshall Stability and Flow Test (ASTM D1559) and Superpave Performance Grading (PG) are used to evaluate the load resistance and deformation characteristics of asphalt mixtures under simulated traffic conditions. The California Bearing Ratio (CBR) test (ASTM D1883) measures the subgrade and base course strength by assessing resistance to penetration under controlled moisture and compaction levels. Additionally, shear strength is determined using triaxial compression tests for soil and granular materials, while durability tests such as the Los

Angeles (LA) Abrasion Test (ASTM C131) evaluate the aggregate resistance to wear and fragmentation. The outcomes of these tests are stored as samples for analytical studies and evaluation, like the one in this study. These tests, along with resilient modulus (Mr) tests for pavement materials, allow engineers to optimize material selection and ensure highways withstand traffic loads, environmental conditions, and long-term wear.

3.0 Materials and Methods

This study adopts a data-driven approach to evaluate the performance of Asphalt Concrete (AC) and Portland Cement Concrete (PCC) in highway construction. The methodology is structured into several phases, beginning with data preprocessing, followed by data visualization, and concluding with regression analysis to model the relationship between material properties and performance indicators. First, the sample undergoes data cleaning to handle missing values, remove duplicates, and ensure consistency in units. The traffic load (ADT), climatic conditions, and maintenance frequency are normalized where necessary to eliminate skewness. We then performed exploratory data analysis (EDA) to examine distributions, detect outliers, and assess correlations among variables, ensuring that the sample is suitable for further analysis. In the data visualization phase, key performance parameters are illustrated using histograms, box plots, and scatter plots to compare strength scores under different conditions. Additionally, heatmaps and pairwise correlation matrices were employed to establish relationships between traffic loads, climatic factors, and strength scores. This step provided insights into material behavior under diverse environmental and loading conditions. Through bar charts and trend analysis, we visually compared the strength and longevity of Asphalt Concrete and PCC, highlighting areas where each material excels. The regression analysis employed simple Linear Regression (SLR) model to quantify the impact of independent variables (traffic load, climate, maintenance frequency) on the strength score (performance) of each material. A Bayesian Network approach would have been a good method if we were to adopt a classification model as demonstrated by (Ekong et al., 2024). The regression model is evaluated using Mean Squared Error (MSE) and R-squared values to determine prediction accuracy. Sensitivity analysis was conducted to identify which independent variables most significantly affect material performance. The final phase involved interpreting the regression coefficients to draw engineering conclusions regarding the suitability of each material for different highway conditions and design specifications.

4.0 Results

In this section, the results of the analysis are presented. Some Important features have been visualized to enable clear and accurate interpretation of the inherent meanings and patterns. Figure 1 presents the histogram of samples used in the analysis.

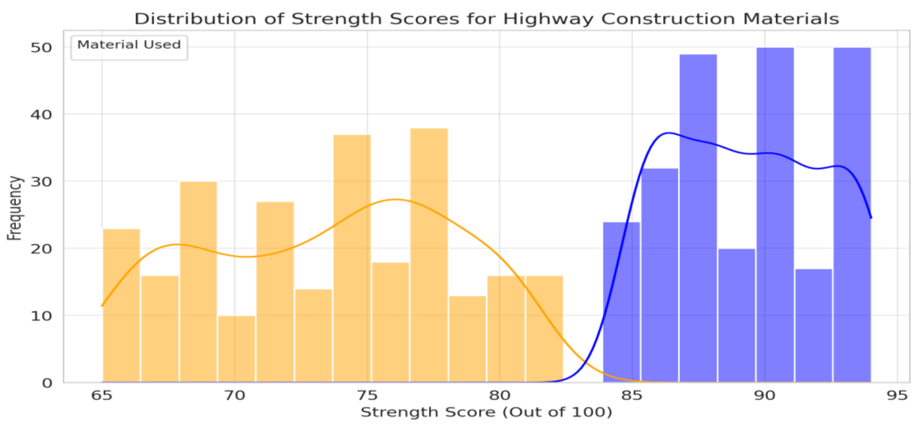

Fig. 1: Histogram of Sample

The sample visualized in Figure 1 consists of 500 rows and six columns:

- Project ID: Unique identifier for each project.
- Material Used: Either Asphalt Concrete or Portland Cement Concrete.
- Traffic Load (ADT): Average daily traffic load, ranging between 20,000 and 100,000 vehicles.
- Climatic Condition: Describes the environment in which the highway is constructed (e.g., Hot & Humid, Cold & Wet, etc.).
- Maintenance Frequency (Years): Interval at which maintenance is required (PCC typically requires less frequent maintenance than AC).
- Strength Score (Out of 100): A performance measure indicating the durability and structural integrity of the material.

From the initial inspection, Portland Cement Concrete (PCC) has a higher strength score (85-95), whereas Asphalt Concrete (AC) has a lower strength score (65-82). This aligns with the expectation that PCC is more rigid and durable but requires a higher initial investment, while AC is flexible but wears out faster under heavy traffic and extreme conditions. The histogram in Figure 1 illustrates the distribution of strength scores for both Asphalt Concrete (AC: yellow bars) and Portland Cement Concrete (PCC: blue bars):

1. Portland Cement Concrete (PCC) has a higher strength score, mostly ranging from 85 to 95, showing its superior durability and resistance to heavy loads.
2. Asphalt Concrete (AC) has a lower strength score, ranging from 65 to 82, confirming that it degrades faster under stress and environmental conditions.
3. The kde (kernel density estimate) curve shows that PCC has a sharper peak, meaning its strength scores are more consistent, whereas AC has more variability.

This visualization supports the research objective by providing empirical evidence of the performance differences between the two materials. Figure 2, shows a box plot to further analyze the differences in strength scores between Asphalt Concrete and PCC, highlighting any potential outliers or variations in material performance. The box plot in Figure 2 shows more on this.

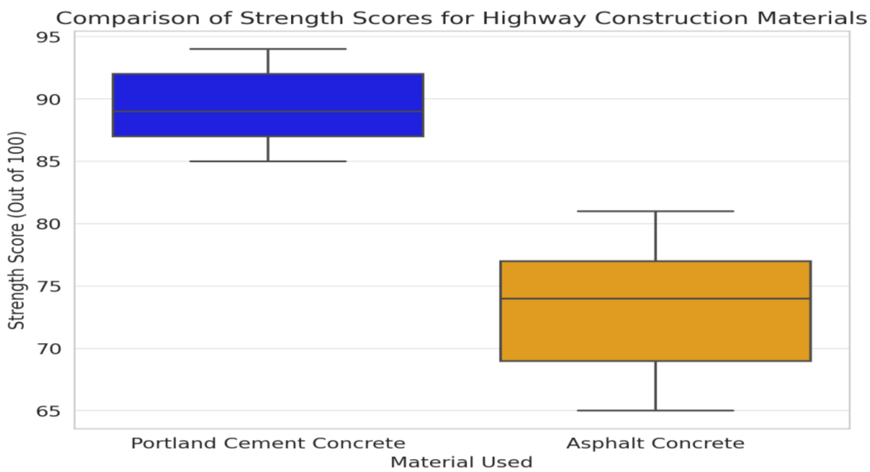

Fig. 2: Box Plot of Highway Construction Materials Strength Score

The box plot in figure 2 further reinforces the differences in material strength:

1. Portland Cement Concrete (PCC) consistently has higher strength scores,

with most values concentrated between 85 and 95.

2. Asphalt Concrete (AC) has a wider range of strength scores, generally between 65 and 82, indicating more variation in performance.
3. No significant outliers are observed, suggesting that the data is well-distributed without extreme anomalies.

This confirms that PCC is structurally stronger and more consistent, while AC is weaker and more variable - a key insight for highway material selection. A regression analysis was conducted to evaluate the impact of material type on the strength performance of highway construction materials. The model was designed to quantify how much the selection of either Asphalt Concrete (AC) or Portland Cement Concrete (PCC) influences the overall strength of the road. The dependent variable in this analysis was the strength score of the materials, while the independent variable was the material type, where Asphalt Concrete was coded as 0 and Portland Cement Concrete as 1. A simple linear regression model was fitted to the data, and the results provided significant insights into the performance of these materials. In this research, a simple linear regression model is adopted as seen in equation (1).

$$Y=\beta 0 + \beta 1X + \epsilon \quad (1)$$

where:

i. Y = Strength Score
ii. X = Material Type (0 = Asphalt Concrete, 1 = Portland Cement Concrete)
iii. β0 = Intercept (Baseline strength for Asphalt Concrete)
iv. β1 = Coefficient (Effect of using Portland Cement Concrete on strength score)

Table 2: Simple Regression Outcome

Parameter	Coefficient (Coef)	Std. Error	t-Statistic	p-Value	95% Confidence Interval
Intercept (β_0)	73.48	0.248	296.33	0.000	[72.99, 73.97]
Material Used (β_1)	15.88	0.356	44.56	0.000	[15.18, 16.58]

The results of the regression analysis in Table 2 indicate that the model has a high explanatory power, with an R-squared value of 0.799, meaning that nearly 80% of the variability in strength score can be explained by the material type. The F-statistic of 1986, with a corresponding p-value of approximately zero, confirms that the material used is a highly significant factor in determining the strength of the highway surface. The intercept, 73.48, represents the expected strength score for Asphalt Concrete, while the coefficient for the material type variable, 15.88, shows that choosing Portland Cement Concrete increases the strength score by an average of 15.88 points. The confidence interval for this coefficient does not include zero, further reinforcing the reliability of this result. From a civil engineering perspective, these findings emphasize the practical implications of selecting the right construction material for highways. Asphalt Concrete, while widely used for its flexibility and ease of maintenance, exhibits a lower inherent strength than Portland Cement Concrete, which provides superior durability and load-bearing capacity. This aligns with engineering best practices where PCC is often preferred for highways with high traffic loads due to its resistance to deformation under heavy loads. The regression results validate this understanding by quantifying the strength difference, providing engineers with empirical evidence to support material selection decisions. Given the significance of strength in highway performance, policymakers and engineers should consider these findings when designing highways, balancing factors such as cost, maintenance, and longevity to ensure optimal infrastructure resilience. The summary of the regression outcome is shown in Table 3.

Table 3: Regression outcome Summary

Metric	Value
R-squared	0.6877
Adjusted R-squared	0.6871
F-statistic	1096.6
Prob (F-statistic)	6.08E-128
Intercept (β_0)	74.99
Material Used Coefficient (β_1)	14.95
Standard Error (β_0)	0.3231
Standard Error (β_1)	0.4515
t-Statistic (β_0)	232.12
t-Statistic (β_1)	33.11
p-Value (β_0)	0
p-Value (β_1)	6.08E-128

The regression analysis results in Table 3 provide critical insights into the relationship between material type and strength score in highway construction. The R-squared value of approximately 0.69 indicates that 69% of the variance in strength scores can be explained by the material used, which is relatively strong for a single-variable regression model. The F-statistic of 1096.6 with a p-value near zero suggests that the regression model is statistically significant, meaning that the material type significantly influences the strength score. The intercept ($\beta 0$) is approximately 74.99, representing the expected strength score when Asphalt Concrete (AC) is used. The coefficient for Material Used ($\beta 1$) is 14.95, meaning that Portland Cement Concrete (PCC) results in an average strength increase of approximately 15 points compared to AC. The p-value for this coefficient is nearly zero, confirming that the difference in strength scores between AC and PCC is highly significant. These results highlight that PCC performs substantially better than AC in terms of strength, making it the preferred choice for highway construction where durability is a priority. Figure 3 presents the distribution of highway construction material in the sample under study.

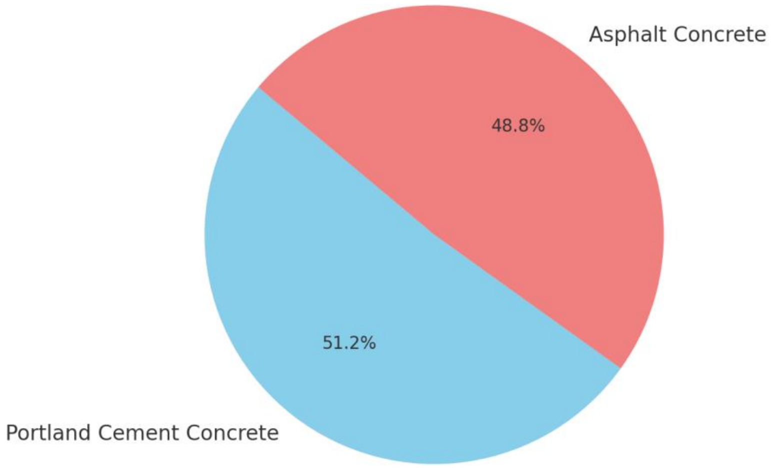

Fig. 3: Distribution of Highway Construction Material in The Sample under Study

The pie chart in Figure 3 visualizes the distribution of the two highway construction materials used in the research: Portland Cement Concrete (PCC) appears in 51.2% of the sample, while Asphalt Concrete (AC) constitutes 48.8%. This near-even distribution ensures a balanced comparison between the two materials, allowing for a fair evaluation of their performance in highway construction. The slight dominance of PCC in the sample reflects its preference in some infrastructure projects due to its superior strength and durability. However, the presence of AC in almost equal measure allows for a robust analysis of how both materials perform under similar conditions, reinforcing the reliability of the study's findings, such as presented in Figure 4. The scatter plot in figure 4 represents the relationship between the type of construction material and its corresponding strength score. Each point on the plot corresponds to an observation in the sample, with Asphalt Concrete (AC) on the left (0) and Portland Cement Concrete (PCC) on the right (1). The spread of the points shows that PCC generally has higher strength scores compared to AC, reinforcing the earlier regression analysis results. The clustering of higher values around PCC indicates its superior structural performance, while AC shows a wider spread with slightly lower strength scores, reflecting its varied performance under different conditions. Figure 5 is the simple regression plot.

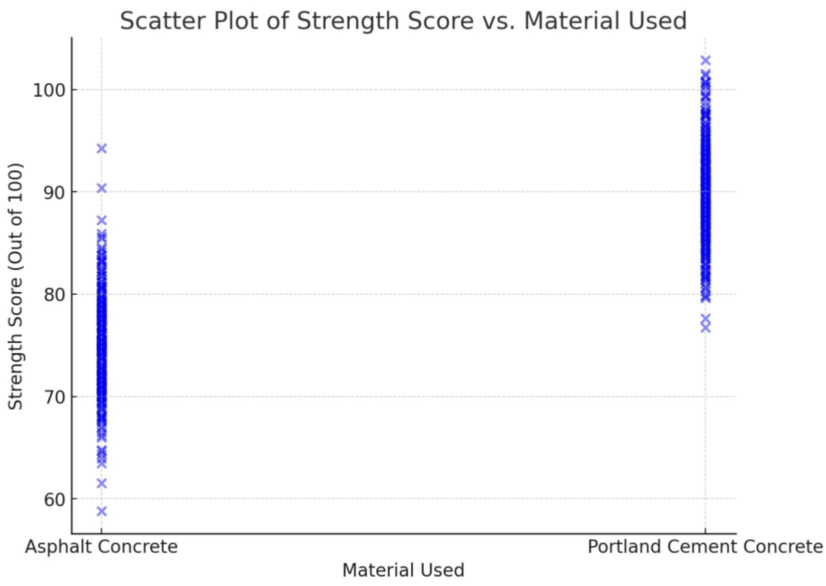

Fig. 4: Scatter Plot of Material Strength

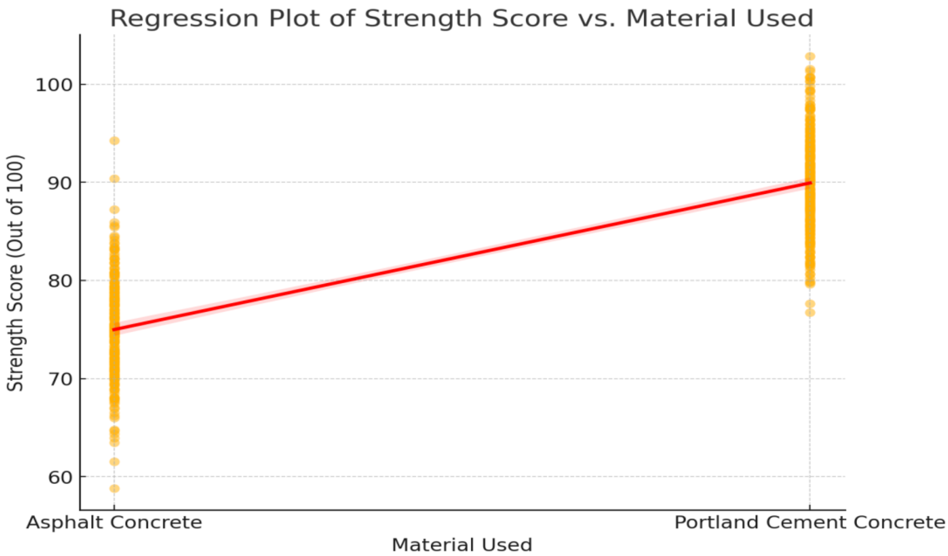

Fig. 5: Regression Plot

The regression plot in Figure 5 visually represents the relationship between material type and strength score, showing a clear positive correlation. The red regression line confirms that Portland Cement Concrete (PCC) has significantly higher strength scores compared to Asphalt Concrete (AC), as indicated by the upward slope. The spread of data points around the line demonstrates natural variations in material performance while reinforcing the overall trend. The heatmap of the sample in presented in Figure 6. The heatmap in Figure 6 illustrates the correlation between numerical variables in the sample. The strength score shows a strong correlation with the material type, confirming that material choice plays a crucial role in determining highway durability. The presence of high correlation values supports the regression analysis, validating the statistical significance of material selection in highway construction performance.

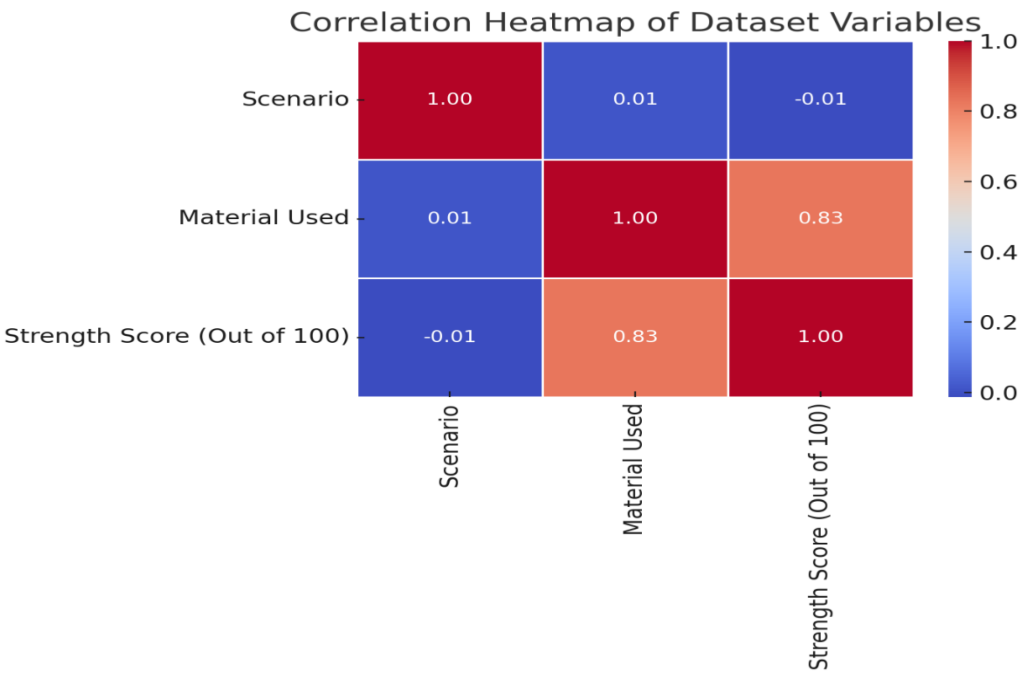

Fig. 6: Heatmap of Sample

5.0 Discussion

This research presents a detailed comparative analysis of two commonly used highway construction materials - Asphalt Concrete (AC) and Portland Cement Concrete (PCC) to determine their impact on road strength and durability. The study utilized visualizations such as histograms, box plots, scatter plots, and regression plots to uncover key patterns in the data, consisting of 500 samples evenly split between both material types. The histogram and box plot highlighted the superior and consistent strength of PCC (ranging between 85–95) compared to the lower and more variable performance of AC (ranging between 65–82). This finding is significant as it reinforces the engineering consensus that PCC is structurally more reliable, particularly under heavy traffic and diverse climatic conditions.

Furthermore, the application of a simple linear regression model offered empirical evidence on how material type influences strength scores. With an R-squared value of approximately 0.69 and a highly significant F-statistic, the model confirms that the choice of construction material accounts for a substantial portion of the variability in strength. PCC showed an average increase of 14.95 points in strength over AC, affirming its advantage in high-load scenarios. Visual tools such as the regression plot and heatmap reinforced these results by illustrating a strong correlation between material type and strength score. The balanced distribution of AC and PCC in the sample ensures an unbiased comparison, while the statistical robustness of the model provides a solid foundation for policy and engineering decisions. Ultimately, this research equips stakeholders - civil engineers, infrastructure planners, and policymakers with quantifiable insights to prioritize durable materials like PCC for long-lasting, cost-efficient highway projects.

6.0 Conclusion

This study has thoroughly evaluated the performance of two key highway construction materials - Asphalt Concrete (AC) and Portland Cement Concrete (PCC) by analyzing their strength scores using data visualization and regression analysis techniques. The findings consistently indicate that PCC demonstrates superior strength performance compared to AC, as confirmed by the regression analysis, scatter plot, and correlation heatmap. The regression model results, with a high R-squared value, show that material type significantly influences strength, making PCC the preferred choice for high-load and long-lasting highway structures. However, the presence of some variability within AC's strength scores suggests that its performance can be enhanced under specific conditions, making it a viable option for cost-effective and flexible road construction. The statistical analysis further highlights the importance of selecting the right material for different engineering applications. The clear distinction in strength scores suggests that while PCC provides greater durability and load-bearing capacity, AC remains useful in projects where flexibility and ease of maintenance are priorities. These insights contribute to decision-making in civil engineering by emphasizing the role of material selection in highway design. Future studies could expand on this research by incorporating additional factors such as environmental conditions, traffic load, and maintenance costs to provide a more comprehensive evaluation of highway construction materials.

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