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Energy Dispersive X-Ray Fluorescence (EDXRF)- Oxide Composition Analysis of Coarse Aggregates and Reclaimed Asphalt Pavement (RAP)as Construction materials

Highlights

- ***Methodology:*** *Used EDXRF analysis.*
- ***Materials:*** *RAP and coarse aggregates.*
- ***Design:*** *Replaced aggregates with RAP at 0%, 25%, 50%, 75%, 100%.*
- ***Testing:*** *Conducted at 7 and 28 days.*
- ***Tests:*** *Compressive, flexural, split tensile strength.*

Graphical Abstract

This study uses EDXRF to analyze how replacing coarse aggregates with varying percentages of RAP influences concrete strength over 7 and 28 days, highlighting optimal performance at 50% and 75% RAP replacements for compressive and split tensile strengths, respectively.

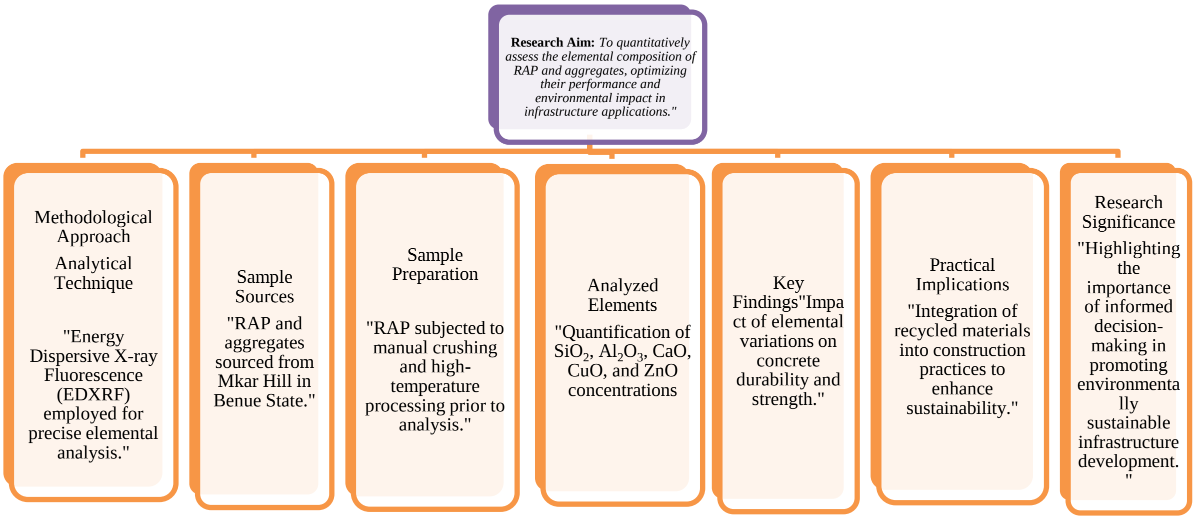

Figure : Graphical Abstract

Aim

The aim of this study is to assess how replacing coarse aggregates with Recycled Asphalt Pavement (RAP) at different percentages affects concrete strength characteristics.

Design &Methodology

The study utilized XRF for chemical analysis of Recycled Asphalt Pavement (RAP) and conducted mechanical tests on concrete samples with varying RAP replacements (0%, 25%, 50%, 75%, and 100%) over 7 and 28 days, employing compressive, flexural, and split tensile strength tests.

Originality

This study's originality lies in its detailed exploration of Recycled Asphalt Pavement (RAP) using XRF and its impact on concrete mechanical properties across various replacement percentages and curing durations.

Findings

The findings indicate that incorporating 50% RAP replacement optimizes compressive strength, with 75% RAP replacement yielding superior split tensile and flexural strengths in concrete.

Conclusion

Optimizing RAP replacement percentages enhances concrete's mechanical properties, supporting sustainable construction practices.

Declaration of Ethical Standards

The authors of this article state that the materials and methods employed in this study did not necessitate ethical committee approval or special legal permissions.

Energy Dispersive X-Ray Fluorescence (EDXRF)-Oxide Composition Analysis of Coarse Aggregates and Reclaimed Asphalt Pavement (RAP) as Construction Materials

Araştırma Makalesi / ResearchArticle

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ABSTRACT

This study utilizes Energy Dispersive X-Ray Fluorescence (EDXRF) to conduct a detailed elemental analysis of Recycled Asphalt Pavement (RAP) and coarse aggregates, focusing on their role in sustainable construction. Elements such as SiO_2, Al_2O_3, CaO, CuO, and ZnO were analyzed, revealing their significant influence on concrete strength, durability, and overall performance. RAP was manually processed and combined with aggregates from Mkar hill in Gboko Local Government Area. The findings show that concrete mixes with 50% RAP replacement achieved the highest compressive strength, while those with 75% RAP replacement excelled in split tensile and flexural strength. These results highlight RAP's effectiveness in enhancing mechanical properties, advocating for its increased use in eco-friendly infrastructure development.

Keywords: Energy Dispersive X-Ray Fluorescence, coarse aggregates, reclaimed asphalt pavement, concrete, mechanical properties, sustainability.

Grozdelerin ve Geri Kazanılmış Asfalt Kaplamalarının (RAP) Yapı Malzemeleri Olarak Enerji Dağılımlı X-Işını Floresans (EDXRF) ile Oksit Kompozisyon Analizi

ÖZ

Bu çalışma, Geri Dönüştürülmüş Asfalt Kaplaması (RAP) ve kaba agregaların sürdürülebilir inşaatlardaki rolüne odaklanarak, Enerji Dağılımlı X-Işını Floresansı (EDXRF) kullanarak kapsamlı bir elemental analiz yapmaktadır. SiO_2, Al_2O_3, CaO, CuO ve ZnO gibi elementler analiz edilerek beton dayanımı, dayanıklılığı ve genel performans üzerindeki önemli etkileri ortaya konulmuştur. RAP, elle işlenmiş ve Gboko Yerel Yönetim Alanı'ndaki Mkar tepesinden alınan agregalarla birleştirilmiştir. Bulgular, %50 RAP ikamesi ile yapılan beton karışımlarının en yüksek basınç dayanımına ulaştığını, %75 RAP ikamesine sahip karışımların ise yarma çekme ve eğilme dayanımında üstün performans gösterdiğini ortaya koymaktadır. Bu sonuçlar, RAP'ın mekanik özellikleri geliştirmedeki etkinliğini vurgulamakta ve çevre dostu altyapı geliştirilmesinde kullanımının artırılması gerektiğini savunmaktadır.

Anahtar Kelimeler: Enerji Dağılımlı X-Işını Floresansı, grozdeler, geri kazanılmış asfalt kaplamaları, beton, mekanik özellikler, sürdürülebilirlik

1.INTRODUCTION

Construction materials play a crucial role in modern society's infrastructure development, necessitating a thorough understanding of their elemental composition to optimize performance, durability, and environmental impact [1]. The composition of these materials directly influences their mechanical properties, environmental resistance, and overall sustainability [2].Recycled Asphalt Pavement (RAP) and coarse aggregates, key constituents in construction, are increasingly recognized for their potential in sustainable building practices [3]. RAP, obtained from reclaimed asphalt, contributes to resource conservation and reduces the environmental footprint associated with asphalt production. Coarse aggregates, integral to concrete and asphalt formulations, significantly affect the structural integrity of construction materials [4].

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The elemental composition of construction materials is fundamental to their mechanical, chemical, and environmental properties. A comprehensive analysis of this composition provides insights into the material's structural characteristics, environmental impacts, and suitability for specific applications [5]. RAP, with its recycled nature, presents a unique opportunity and challenge for investigation. Understanding its elemental composition is crucial to ensure compatibility with traditional construction materials and its contribution to sustainable infrastructure [5]. The use of RAP aligns with sustainable construction practices by reducing the demand for virgin materials, conserving energy, and minimizing the carbon footprint associated with new asphalt production [6]. Investigating its elemental composition is essential for evaluating its performance and environmental benefits [6]. Coarse aggregates, as essential components of concrete and asphalt mixes, directly impact the mechanical properties of resulting construction material. Optimizing the elemental composition of coarse aggregates enhances the overall durability and sustainability of construction projects [7]. Figure 1 illustrates the sources of the mentioned coarse Aggregates.

Figure 1: The source of the coarse Aggregates

This study, considered the elemental analysis of RAP and coarse aggregates using Energy Dispersive X-Ray Fluorescence (EDXRF) to provide valuable insights into their chemical makeup and potential implications for sustainable construction practices. The subsequent sections will detail the methodology, results, and implications of our investigation.

The primary objective of this study is to conduct a detailed analysis and characterization of the elemental composition, with a specific focus on oxide composition, of Recycled Asphalt Pavement (RAP) and coarse aggregates. The study employs Energy Dispersive X-Ray Fluorescence (EDXRF) as the analytical technique to achieve a comprehensive understanding of the oxide content present in these construction materials.This study's originality lies in its comprehensive analysis of elemental composition and mechanical properties of Recycled Asphalt Pavement (RAP) and coarse aggregates, particularly emphasizing sustainable construction practices and its applicability to the local context in Wannune, Benue State, Nigeria.

1.1 Implications Elemental and Oxide Compositions of RAP for Sustainable Construction:

The study explores two overarching questions related to the implications for sustainable construction: How do the elemental and oxide compositions of RAP align with sustainable construction practices? What insights do the oxide profiles provide in terms of the environmental impact and performance of these construction materials? Addressing these research questions will provide a comprehensive understanding of the chemical makeup of RAP and coarse aggregates, offering insights into their potential applications in sustainable construction. Subsequent sections of this study will present the methodology, results, and discussions aimed at providing comprehensive answers to these research questions.

1.2. Location of Study

1.2.1. A Sustainable approach to asphalt recycling:

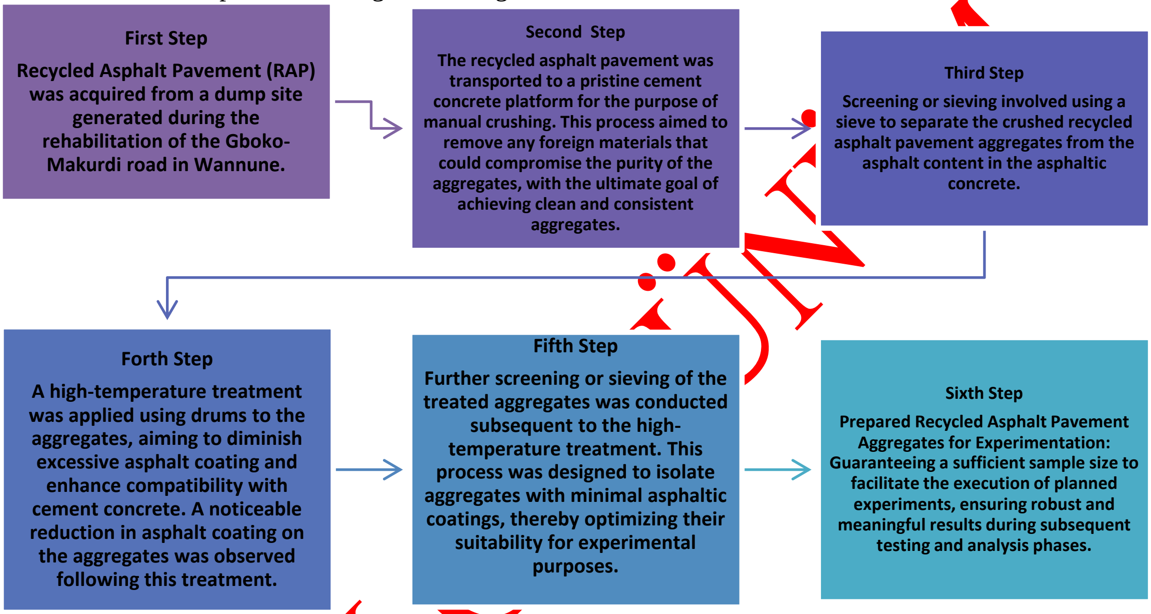
The RAP used in this study was sourced from the Gboko-Makurdi Federal Highway in Wannune, Tarka, Benue State, Nigeria. Geographically located at approximately 7.562397° latitude and 8.885954° longitude (7°33'44.63"N latitude and 8°53'9.43"E longitude), Wannune served as a dumpsite for reclaimed asphalt material obtained from a road rehabilitation process over a decade ago. The specific details and geographic features of Wannune, as illustrated in Figure 1, are crucial for understanding its strategic significance and logistical accessibility in procuring samples for analysis.

Coarse Aggregates Granite: The coarse aggregates granite utilized in this study was extracted from Mkar hill at the Hajaig Construction Ltd Quarry site. Mkar is located in Gboko Local Government Area, Benue State, Nigeria, with geographical coordinates approximately at 7.2945° latitude and 9.0095° longitude (7°17'40.2"N latitude and 9°00'34.2"E longitude). The granite obtained from Mkar hill plays a vital role in the research, contributing insights into the chemical composition of coarse aggregates. Understanding the geographic location of Mkar is essential for grasping the specific site from which the coarse aggregates were sourced for analysis. Both samples were collected from two distinct locations within Benue State: Wannune in Tarka Local Government Area and Mkar in Gboko Local Government Area. These locations, as depicted in Figure 2 below, provide a diverse range of material sources for the study.

Figure 2: Representation of Benue state the main location for the collection of samples of this study on the Map of Nigeria

1.3. Processing of RAP

The preparation of Recycled Asphalt Pavement (RAP) aggregates involved a meticulous and systematic procedure to ensure uniformity and cleanliness for subsequent use in construction materials[7]. Initially, the RAP aggregates underwent manual crushing on a clean cement concrete platform, aiming to achieve consistent particle size and cleanliness crucial for their performance in construction applications[8]. However, this manual crushing resulted in significant asphalt coating on the RAP aggregates, prompting the need for further treatment. To address this, the aggregates underwent a specialized high-temperature treatment using drums, designed to reduce the asphalt coating and enhance compatibility with concrete materials. Following this treatment, additional sieving was performed to isolate aggregates with minimal asphaltic coatings, ensuring they met specific cleanliness and size criteria for optimal integration into construction materials[9]. Figure 3 visually summarizes this step-wise procedure, providing a clear representation of the processes involved in preparing RAP aggregates for sustainable construction practices.Reference is made to Figure 4a, depicting asphaltic material with aggregates in crumbs; Figure 4b, illustrating the crushing of RAP (Recycled Asphalt Pavement); Figure 4c, showing the post-crushing state coated with a significant amount of asphalt; and Figure 4d, representing the sieving process after subjecting the material to high temperature."



First Step

Recycled Asphalt Pavement (RAP) was acquired from a dump site generated during the rehabilitation of the Gboko-Makurdi road in Wannune.

Second Step

The recycled asphalt pavement was transported to a pristine cement concrete platform for the purpose of manual crushing. This process aimed to remove any foreign materials that could compromise the purity of the aggregates, with the ultimate goal of achieving clean and consistent aggregates.

Third Step

Screening or sieving involved using a sieve to separate the crushed recycled asphalt pavement aggregates from the asphalt content in the asphaltic concrete.

Forth Step

A high-temperature treatment was applied using drums to the aggregates, aiming to diminish excessive asphalt coating and enhance compatibility with cement concrete. A noticeable reduction in asphalt coating on the aggregates was observed following this treatment.

Fifth Step

Further screening or sieving of the treated aggregates was conducted subsequent to the high-temperature treatment. This process was designed to isolate aggregates with minimal asphaltic coatings, thereby optimizing their suitability for experimental purposes.

Sixth Step

Prepared Recycled Asphalt Pavement Aggregates for Experimentation: Guaranteeing a sufficient sample size to facilitate the execution of planned experiments, ensuring robust and meaningful results during subsequent testing and analysis phases.

Figure 3: Summary of the Process of Reclamation

Figure 4a: Asphaltic material with aggregates in Crumbs

Figure 4b: Crushing of RAP

Figure 4c: Post- Crushing

Figure 4d: Sieving Process

2. LITERATURE REVIEW

2.1. Overview of EDXRF Analysis

Energy Dispersive X-Ray Fluorescence (EDXRF) stands as a robust analytical technique widely employed for material analysis due to its non-destructive nature and high sensitivity[8]. At its core, EDXRF operates on the principles of X-ray excitation, where a sample is irradiated with high-energy X-rays generated by an X-ray tube. These incident X-rays interact with the inner-shell electrons of atoms within the sample, leading to the ejection of these electrons. The subsequent characteristic X-ray emission occurs as outer-shell electrons transition to fill the vacancies left by the ejected inner-shell electrons. The energy of these emitted X-rays is unique to each element, forming the basis for qualitative and quantitative analysis. Detection of these X-rays is carried out using an energy-dispersive detector, generating a spectrum that corresponds to the elemental composition of the sample[8].

EDXRF finds applications across diverse fields, including material analysis, environmental monitoring, quality control in industry, and contributions to archaeology and art conservation. Its non-destructive nature is particularly advantageous for studying valuable or irreplaceable materials, and its rapid analysis capabilities make it suitable for both research and industrial applications where quick elemental insights are essential. In the context of this study, the EDXRF technique serves as a pivotal tool for the analysis and characterization of the elemental and oxide composition of Recycled Asphalt Pavement (RAP) and coarse aggregates [9]. The subsequent sections will delve into the specific methodology applied in this study, showcasing how EDXRF's capabilities are harnessed to gain comprehensive insights into the chemical makeup of these construction materials.

2.2. Chemical Composition of RAP (Recycled Asphalt Pavement)

Recycled Asphalt Pavement (RAP) represents a sustainable approach to road construction, where the chemical composition plays a pivotal role in determining its performance and environmental impact. The intricate amalgamation of bitumen, aggregates, and mineral fillers defines the chemical makeup of RAP[10].

Bitumen, a central component in asphalt, constitutes a complex blend of hydrocarbons. The recycling process introduces aged bitumen from the reclaimed pavement, altering its viscosity and rheological properties. The chemical modifications in recycled bitumen have implications for the overall binder performance in RAP mixes, influencing aspects such as adhesion and durability[11].

Aggregates, forming a substantial portion of RAP, encompass a diverse range of minerals. Predominant among these are silicate minerals like quartz, feldspar, and mica. The chemical composition of these minerals profoundly influences the mechanical properties of the asphalt mix. Additionally, RAP may contain aggregates with coatings of residual asphalt, adding a layer of complexity to the overall binder-aggregate interaction[12].

Mineral fillers, often introduced during the initial asphalt mix, contribute to the chemical composition of RAP. Materials like limestone dust or hydrated lime serve as mineral fillers, influencing the properties of the recycled asphalt. The interplay of these components underscores the need for a nuanced understanding of the chemical intricacies inherent in RAP[13].

The oxide composition further delineates the chemical profile of RAP. Common oxides, including silicon dioxide (SiO_2) from quartz, aluminum oxide (Al_2O_3) from feldspar, and iron oxide (Fe_2O_3) from various minerals, are integral to the overall composition. The presence of these oxides plays a crucial role in assessing the reactivity of RAP and its potential impact on the mechanical and environmental properties of recycled asphalt [14].

2.3 Chemical Composition of Coarse Aggregates

Coarse aggregates, essential in the construction of concrete and asphalt mixes, exhibit a rich chemical composition derived from diverse rock types. The amalgamation of silicate minerals, calcium carbonate, iron oxides, and alkalis shapes the chemical characteristics of coarse aggregates, influencing the performance of construction materials. Silicate minerals, such as quartz, feldspar, and mica, constitute the primary chemical components of coarse aggregates. Silicon dioxide (SiO_2) predominates in these minerals, imparting strength and durability to concrete. The diversity of rock sources introduces variations in the silicate mineral composition, contributing to the unique properties of different aggregates[15].

Aggregates derived from limestone or dolomite contain calcium carbonate ($CaCO_3$). This component influences the alkalinity of concrete mixes and plays a role in the carbonation process over time. The presence of calcium carbonate introduces considerations related to both mechanical strength and long-term durability in concrete structures. Iron oxides contribute to the coloration of aggregates[16]. Minerals like hematite and magnetite add distinct hues to the visual appearance of concrete. Beyond aesthetics, the presence of iron oxides can also influence the material's thermal properties and overall resilience. Alkali and alkaline earth elements, including sodium, potassium, calcium, and magnesium, exist in varying concentrations in coarse aggregates. These elements can influence the reactivity of aggregates with alkali in the cement, potentially leading to alkali-aggregate reactions that impact the long-term durability of concrete structures [17].

2.4. Mechanical Properties of RAP

The mechanical properties of Reclaimed Asphalt Pavement (RAP) are crucial considerations in pavement engineering and construction. RAP, a recycled material derived from reclaimed asphalt, offers sustainability benefits by reducing the need for virgin materials and minimizing environmental impacts associated with asphalt production. Understanding the mechanical properties of RAP is essential for evaluating its performance and suitability for various applications [18]. Key mechanical properties include its stiffness, strength, durability, and resistance to deformation and cracking under traffic loads. Mechanical testing methods such as the Marshall Stability Test, Indirect Tensile Strength Test, and Dynamic Modulus Test are commonly used to assess these properties [19]. The influence of RAP content on mechanical properties is significant, with higher RAP percentages often leading to changes in mixture stiffness and fatigue resistance. However, challenges such as variability in RAP characteristics, binder aging, and moisture sensitivity must be addressed to ensure consistent performance. Research in this area focuses on optimizing RAP mix designs, developing innovative testing methods, and implementing strategies for sustainable pavement construction [20]. Overall, a comprehensive understanding of the mechanical properties of RAP is essential for promoting its widespread use and advancing sustainable infrastructure practices.

2.5. Environmental Impact of RAP

The environmental impact of Reclaimed Asphalt Pavement (RAP) is a critical consideration in sustainable construction practices and pavement engineering. RAP, derived from recycled asphalt materials, offers numerous environmental benefits compared to traditional pavement materials [21]. One significant advantage is the reduction of waste generated from asphalt demolition and removal, thereby decreasing the demand for landfill space and mitigating environmental pollution [22]. Additionally, by reusing RAP in new asphalt mixes, there is a substantial reduction in the consumption of virgin materials such as aggregates and bitumen, leading to conservation of natural resources and decreased energy consumption associated with material extraction and processing. Furthermore, incorporating RAP into asphalt mixes reduces greenhouse gas emissions and carbon footprint by lowering energy-intensive production processes involved in manufacturing new asphalt materials [23]. However, challenges such as potential leaching of contaminants from RAP and the need for proper management of RAP stockpiles and processing facilities must be addressed to minimize environmental risks. Overall, the environmental impact of RAP is largely positive, contributing to sustainable infrastructure development and paving the way for greener construction practices in the asphalt industry [24].

2.5.1. Environmental benefits of RAP

The utilization of Reclaimed Asphalt Pavement (RAP) in construction offers several significant environmental benefits that contribute to sustainable infrastructure development [25]. One of the primary advantages is the reduction of waste generated from asphalt demolition and removal, which minimizes the burden on landfills and reduces environmental pollution associated with waste disposal [26]. By recycling and reusing RAP in new asphalt mixes, the demand for virgin materials such as aggregates and bitumen is substantially reduced, leading to conservation of natural resources and decreased energy consumption during material extraction and processing [27]. Moreover, incorporating RAP into asphalt mixes helps to lower greenhouse gas emissions and overall carbon footprint by reducing the need for energy-intensive production processes involved in manufacturing new asphalt materials. Additionally, the use of RAP promotes circular economy principles by extending the lifespan of asphalt materials and minimizing the need for continuous extraction of raw materials [28]. Overall, the environmental benefits of RAP contribute to more sustainable construction practices, making it a valuable component in paving the way towards greener and more eco-friendly infrastructure development.

2.6. Economic Benefits of RAP

The integration of Reclaimed Asphalt Pavement (RAP) in construction projects offers numerous economic advantages that enhance the overall cost-effectiveness and sustainability of infrastructure development [29]. One of the primary economic benefits of RAP is its ability to reduce material costs associated with asphalt pavement construction. By incorporating recycled RAP materials into new asphalt mixes, construction companies can significantly lower expenses related to the procurement of virgin aggregates and bitumen, as well as the transportation and disposal of waste materials generated from asphalt demolition [30]. Additionally, RAP utilization helps to extend the service life of roadways and pavements, reducing the frequency of maintenance and repair cycles and resulting in long-term cost savings for transportation agencies and taxpayers. Moreover, the availability of RAP materials locally or regionally reduces reliance on distant sources of raw materials, further decreasing transportation costs and fuel consumption associated with material transport [31]. Furthermore, the adoption of RAP supports job creation and economic growth by fostering the development of recycling infrastructure and paving the way for a more sustainable construction industry. Overall, the economic benefits of RAP contribute to improved project efficiency, reduced lifecycle costs, and enhanced competitiveness in the construction sector, making it a valuable asset for achieving economic sustainability in infrastructure projects [32].

2.7 Challenges and Limitations of RAP

While Reclaimed Asphalt Pavement (RAP) offers various advantages in construction, it also presents several challenges and limitations that need to be addressed for its effective utilization. One significant challenge is the variability in RAP material properties, including gradation, asphalt content, and moisture content, which can affect the performance and consistency of recycled asphalt mixes [33]. Managing and controlling this variability requires sophisticated quality control measures and testing protocols to ensure compliance with specifications and performance standards. Another challenge is the potential presence of contaminants in RAP, such as asbestos, lead, and other hazardous materials, which may pose health and environmental risks if not properly identified and managed during processing and handling [34]. Adequate screening and remediation procedures are necessary to mitigate these risks and ensure the safety of workers and the surrounding community.

Furthermore, the aging and degradation of asphalt binder in RAP over time can impact the performance and durability of recycled asphalt mixes, leading to reduced stiffness, increased susceptibility to cracking, and diminished resistance to moisture damage and fatigue[35]. Addressing these issues requires innovative recycling technologies and rejuvenators to restore the properties of aged asphalt binder and enhance the overall performance of recycled asphalt mixes. Additionally, the limited availability and accessibility of high-quality RAP materials in certain regions may constrain its widespread adoption and necessitate the development of efficient logistics and supply chain management strategies to optimize resource utilization and minimize transportation costs[36].

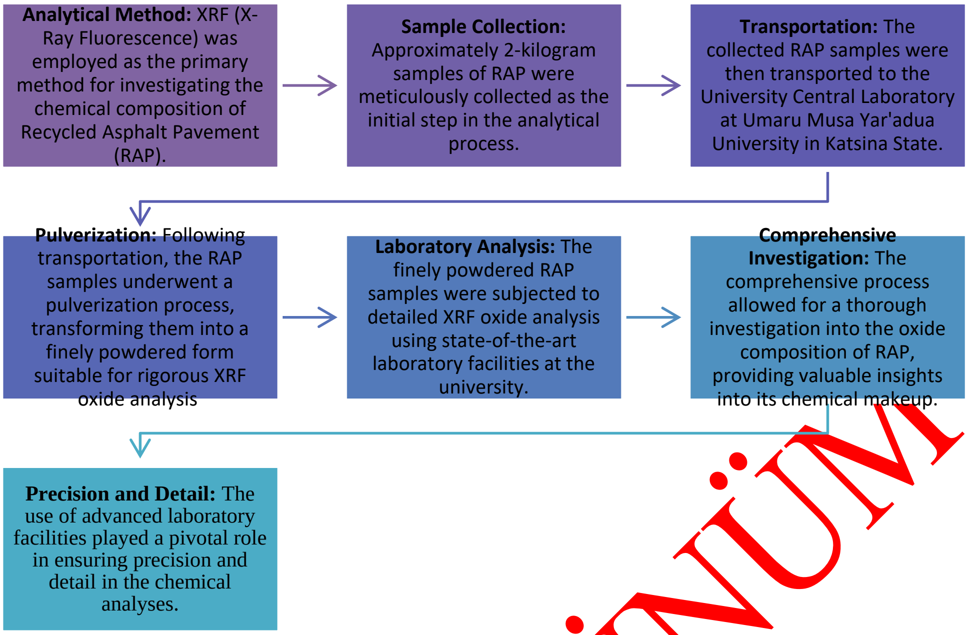
Moreover, regulatory barriers and specifications governing the use of RAP in construction projects may vary between jurisdictions and impose restrictions on its application, hindering its full potential as a sustainable pavement solution[37]. Overcoming these regulatory hurdles requires collaboration between industry stakeholders, policymakers, and regulatory agencies to harmonize standards, streamline permitting processes, and promote the responsible use of RAP in accordance with environmental and safety guidelines. Finally, the upfront costs associated with equipment upgrades, processing facilities, and specialized technologies for RAP recycling may pose financial barriers for small contractors and municipalities looking to invest in sustainable pavement solutions. Access to funding mechanisms, incentives, and technical assistance programs can help offset these costs and encourage greater adoption of RAP in construction projects, fostering economic growth and environmental stewardship in the infrastructure sector [38-40].

3.0 MATERIALS AND METHODS

3.1 Sample Collection

The study employed XRF (X-Ray Fluorescence) as the primary analytical method to explore the chemical composition of Recycled Asphalt Pavement (RAP). Initial steps involved the meticulous collection of approximately 2-kilogram RAP and coarse aggregate samples which were weighed using a 100kg capacity Camry weighing balance as shown in figure 5, which were then transported to the University Central Laboratory at Umaru Musa Yar'adua, University in Katsina State. Subsequent to transportation, the samples underwent a pulverization process, transforming them into a finely powdered form suitable for rigorous XRF oxide analysis. The state-of-the-art laboratory facilities at the university played a pivotal role in ensuring precision and detail in the chemical analyses.During the experimentation of the mechanical properties of concrete, cube samples measuring 150x150x150mm were cast for compressive strength tests, beams measuring 150x150x300 mm were prepared for flexural strength tests, and cylindrical samples with a width of 150mm and a height of 300mm were used for split tensile tests. These samples were cured for 7 and 28 days before being subjected to crushing tests.

Figure 5: 100kg capacity Camry weighing balance



Analytical Method: XRF (X-Ray Fluorescence) was employed as the primary method for investigating the chemical composition of Recycled Asphalt Pavement (RAP).

Sample Collection: Approximately 2-kilogram samples of RAP were meticulously collected as the initial step in the analytical process.

Transportation: The collected RAP samples were then transported to the University Central Laboratory at Umaru Musa Yar'adua University in Katsina State.

Pulverization: Following transportation, the RAP samples underwent a pulverization process, transforming them into a finely powdered form suitable for rigorous XRF oxide analysis

Laboratory Analysis: The finely powdered RAP samples were subjected to detailed XRF oxide analysis using state-of-the-art laboratory facilities at the university.

Comprehensive Investigation: The comprehensive process allowed for a thorough investigation into the oxide composition of RAP, providing valuable insights into its chemical makeup.

Precision and Detail: The use of advanced laboratory facilities played a pivotal role in ensuring precision and detail in the chemical analyses.

Figure 6: Processes involved in Oxide Analysis

Figure7a: Pictorial Representation of Samples for testing

Figure: 7ba: Pulverized RAP undergoing Sieve Analysis

4.0 FINDINGS, RESULTS AND DISCUSSİON.

4.1 XRF-Oxide analysis of the Recycled Asphalt Pavement (RAP)

The XRF-Oxide analysis of the Recycled Asphalt Pavement (RAP) sample offers a detailed insight into its elemental composition, vital for evaluating its potential applications in construction. Iron(III) oxide (Fe_2O_3) constitutes 2.3182% of the sample, influencing both the color and strength of the asphalt, crucial for its overall durability in construction projects. Silicon dioxide (SiO_2), dominating at 45.045%, signifies a substantial presence of aggregates essential for providing structural stability to the asphalt mix in construction applications.Aluminum oxide (Al_2O_3), with a concentration of 10.584% and a peak at 165 cps/mA, enhances the asphalt's resistance to aging, playing a pivotal role in ensuring the material's durability in pavement construction. Magnesium oxide (MgO), at 2.87%, contributes to the material's physical properties and resistance against environmental factors, important considerations in construction contexts.

Phosphorus pentoxide (P_2O_5), found in trace amounts (0.2217%), may subtly influence the adhesion properties of the material in construction applications. Sulfur trioxide (SO_3), present at 0.3254%, can impact the rheological properties of asphalt, affecting its workability and long-term performance in construction. Titanium dioxide (TiO_2), at 0.446%, contributes to the material's resistance to UV radiation, enhancing its longevity in construction projects. These oxides collectively shape the properties of the Recycled Asphalt Pavement, influencing its durability, adhesion, and resistance to environmental factors. The concentrations and types of oxides play pivotal roles in determining the material's performance characteristics, crucial considerations for its application in construction works. These details are captured in the figure 8 shows the graphical representation.

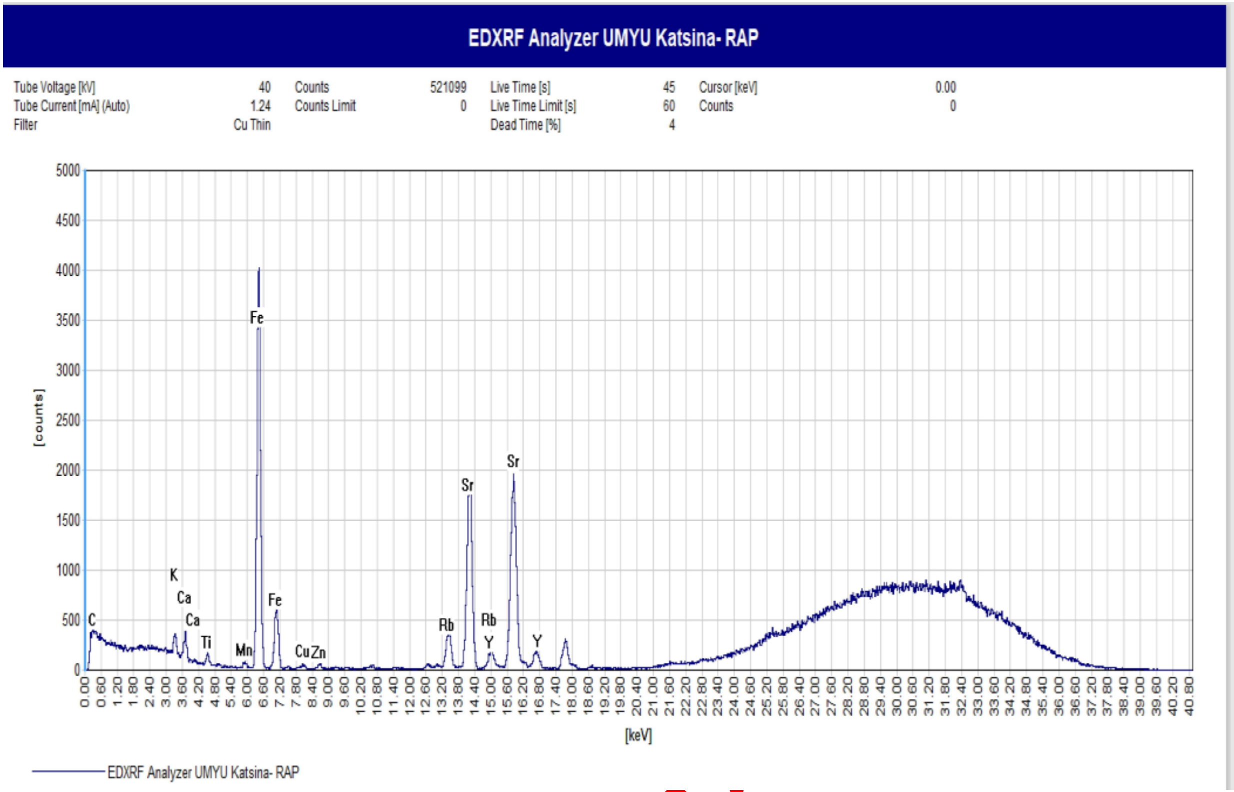


Figure 8: Graphical representation of XRF-Oxide results of RAP from Wannune Town

4.2 XRF-Oxide result of Coarse aggregates (CA)from Mkar Hill

The XRF-Oxide analysis of Coarse Aggregates (CA) from Mkar Hill reveals a diverse array of oxides, each playing a significant role in influencing the material's properties for potential applications in construction. Iron(III) oxide (Fe2O3) constitutes 2.3929% of the sample, contributing to both color and strength, crucial factors for the durability of construction materials. Silicon dioxide (SiO2) dominates at 53.931%, signifying a substantial presence of aggregates essential for structural stability in construction applications.Aluminum oxide (Al2O3), with a concentration of 11.37% and a peak at 177 cps/mA, enhances the resistance to aging in the material, ensuring its durability in pavement construction. Magnesium oxide (MgO), at 2.37%, contributes to the physical properties and resistance against environmental factors, vital considerations in construction contexts.

Phosphorus pentoxide (P2O5), found in trace amounts (0.4067%), may subtly influence the adhesion properties of the material in construction applications. Sulfur trioxide (SO3), present at 0.0561%, can impact the rheological properties of aggregates, affecting workability and long-term performance in construction. Titanium dioxide (TiO2), at 0.3339%, contributes to the material's resistance to UV radiation, enhancing longevity in construction projects.The analysis further reveals the presence of various metal oxides in the Coarse Aggregates. For instance, Calcium oxide (CaO) is found at 1.4997%, and Potassium oxide (K2O) at 4.092%, both contributing to the material's overall composition and performance in construction. Copper(II) oxide (CuO) and Zinc oxide (ZnO) are present in trace amounts, while Chromium(III) oxide (Cr2O3) and Vanadium(V) oxide (V2O5) are detected in minor concentrations.

Additionally, the analysis identifies the presence of nonmetals such as Phosphorus pentoxide (P2O5), Sulfur trioxide (SO3), and Chlorine (Cl) in the Coarse Aggregates. Each of these nonmetals plays a role in influencing specific properties of the material, contributing to its overall suitability for construction applications.The concentration of metalloids, including Arsenic(III) oxide (As2O3) and Antimony(III) oxide (Sb2O3), is negligible, suggesting minimal impact on the material's characteristics in construction.The detailed analysis extends to various other oxides, each with its unique concentration and peak values. While some oxides are not detected, indicating their absence or being below the detection limit, others are present in measurable quantities, contributing to the overall chemical composition of the Coarse Aggregates from Mkar Hill.

In conclusion, the comprehensive analysis of these oxides provides valuable insights into the chemical makeup of Coarse Aggregates, influencing their durability, adhesion, and resistance to environmental factors. These considerations are crucial for understanding the potential applications of the material in construction works, allowing for informed decision-making in sustainable and effective construction practices. These details are captured in the figure 9 shows the graphical representation.

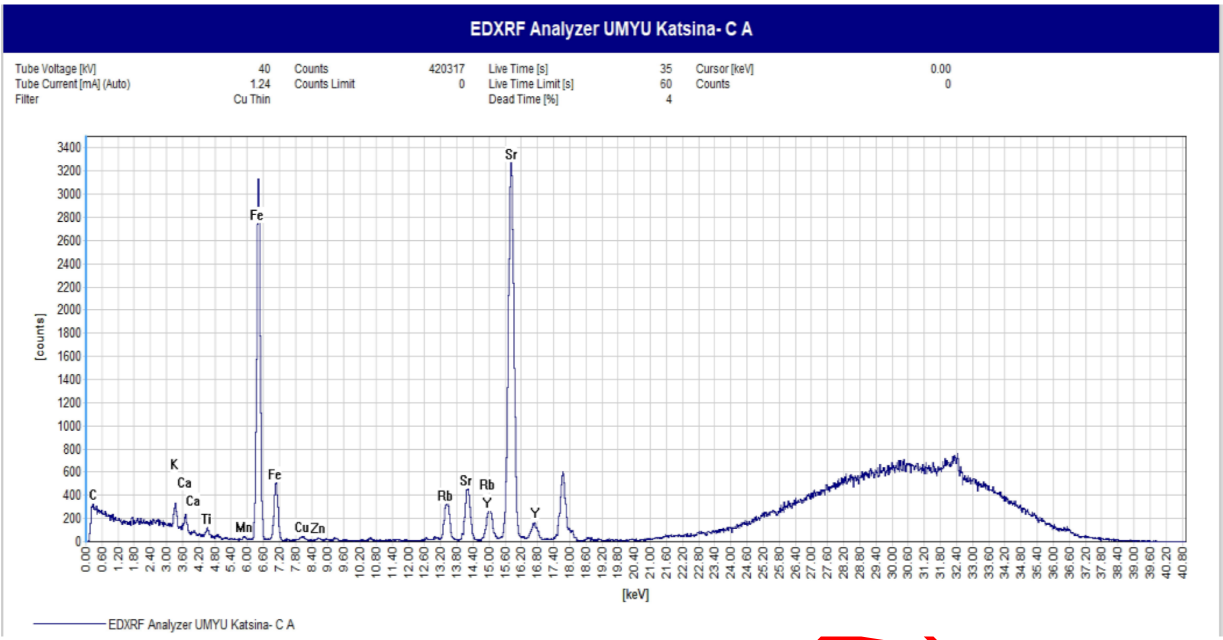


Figure 9: Graphical representation of XRF-Oxide results of Coarse Aggregates(Granite) from Mkar Hill

4.3 Comparative Analysis

The analysis of the 39 oxides found in both Coarse Aggregates (CA) and Recycled Asphalt Pavement (RAP) reveals intriguing insights into their concentrations and potential implications for construction materials. Among the metals, Iron(III) Oxide (Fe2O3) displays a slight decrease in RAP, impacting color and strength in concrete. Silicon Dioxide (SiO2) exhibits a significant decrease in RAP, raising concerns about potential alterations in concrete's long-term durability due to its crucial role in influencing strength. Aluminum Oxide (Al2O3) and Magnesium Oxide (MgO) show minor concentration changes, impacting hardness, durability, and setting time.Phosphorus Pentoxide (P2O5) and Sulfur Trioxide (SO3) display slight decreases in RAP, influencing setting time and strength. Titanium Dioxide (TiO2) and Manganese (II) Oxide (MnO) exhibit minor increases in RAP, potentially affecting whiteness, opacity, and color. Calcium Oxide (CaO) significantly increases in RAP, impacting cement hydration. Potassium Oxide (K2O) decreases, potentially influencing strength and durability. Copper (II) Oxide (CuO) and Zinc Oxide (ZnO) show low concentrations with minimal impact.

Moving to the nonmetals, Chlorine (Cl) displays trace amounts in both samples, likely with minimal influence. Zirconium Dioxide (ZrO2) exhibits a higher concentration in CA, contributing to enhanced strength and durability. Tantalum(V) Oxide (Ta2O5) shows similar concentrations in both samples with limited impact. Bromine (Br) is absent in both samples. Strontium Oxide (SrO) increases in RAP, indicating potential differences in material properties.Niobium(V) Oxide (Nb2O5) and Bismuth (III) Oxide (Bi2O3) maintain comparable concentrations. Antimony (III) Oxide (Sb2O3) increases in CA, potentially impacting material properties. Cobalt (II, III) Oxide (Co3O4) is absent in both samples. Cadmium Oxide (CdO) shows negligible concentrations. Hafnium Dioxide (HfO2) maintains similar concentrations.

Continuing with the remaining elements, Silver(I) Oxide (Ag2O) is absent in both samples, while Cerium (IV) Oxide (CeO2) exhibits a slightly higher concentration in CA. Barium Oxide (BaO) increases in RAP, suggesting differences in material properties. Gold (Au) shows minimal concentrations in both samples. Negative concentrations in Tungsten (VI) Oxide (WO3) and Molybdenum (VI) Oxide (MoO3) may indicate analytical artifacts or absence.

Lanthanum (III) Oxide (La2O3) and Thorium Dioxide (ThO2) are absent in both samples. Tin (IV) Oxide (SnO2) increases in CA, indicating potential variations in material characteristics.

In summary as shown in table 1, the analysis showcases nuanced variations in oxide concentrations between CA and RAP. These variations, often within acceptable ranges, highlight the potential impact on properties like color, strength, and durability in construction materials, underscoring the importance of detailed analysis in sustainable material practices. The use of recycled materials, as seen in RAP, demonstrates a viable option for construction, maintaining material integrity while contributing to sustainability efforts.

Table 1: Comparative Analysis of Oxide Concentrations in Coarse Aggregates and Recycled Asphalt Pavement for Construction Applications

Serial No.	Element	Concentration (%) CA	Concentration (%) RAP	Peak (cps/mA) CA	Peak (cps/mA) RAP	Chemical Name	Category	Implicationsfor Construction
1	Fe2O3	2.3929	2.3182	8902	8625	Iron(III) oxide	Metal	Adds color and strength to concrete; higher concentrations may impact concrete's workability and set time.
2	SiO2	53.931	45.045	4034	3369	Silicon dioxide	Nonmetal	Major component in aggregates; influences concrete's strength and durability. High concentrations may lead to alkali-silica reaction, affecting long-term durability.
3	Al2O3	11.37	10.584	177	165	Aluminum oxide	Metal	Enhances hardness and durability of concrete; excessive amounts can slow down the setting time.
4	MgO	2.37	2.87	3	4	Magnesium oxide	Metal	Affects concrete's setting time; higher concentrations may lead to expansion and cracking.
5	P2O5	0.4067	0.2217	86	47	Phosphorus pentoxide	Nonmetal	Influences concrete's setting time and strength; higher concentrations may act as a retarder.
6	SO3	0.0561	0.3254	31	178	Sulfur trioxide	Nonmetal	Affects concrete's strength and durability; excessive amounts may lead to sulfate attack.
7	TiO2	0.3339	0.446	1204	1609	Titanium dioxide	Metal	Enhances whiteness and opacity of concrete; higher concentrations may influence workability.
8	MnO	0.1302	0.2753	394	834	Manganese(II) oxide	Metal	Influences concrete's color; higher concentrations may impact concrete's setting time.
9	CaO	1.4997	2.4127	2229	3585	Calcium oxide	Metal	Participates in cement hydration; excessive amounts may lead to flash setting.
10	K2O	4.092	3.2766	4315	3455	Potassium oxide	Metal	Influences concrete's strength and durability; excessive amounts may impact workability.
11	CuO	0.00493	0.00341	16	11	Copper(II) oxide	Metal	Low concentrations with minimal impact on the overall material characteristics.
12	ZnO	0.0096	0.01664	52	91	Zinc oxide	Metal	RAP exhibits higher ZnO, potentially influencing the material's properties.
13	Cr2O3	0	0.00278	0	22	Chromium(III) oxide	Metal	Low concentrations with limited impact on the material's chemical composition.
14	V2O5	0.00314	0.00875	21	58	Vanadium(V) oxide	Metal	Higher V2O5 in RAP may contribute to its overall material characteristics.

15	As2O3	0	0	0	0	Arsenic(III) oxide	Metalloid	Both samples show no presence of arsenic oxide.
16	PbO	0.00482	0.0092	2	4	Lead(II) oxide	Metal	Low concentrations in both samples with minimal impact.
17	Rb2O	0.0101	0.00819	54	43	Rubidium oxide	Metal	Similar concentrations with limited influence on material properties.
18	Ga2O3	0.00265	0.00262	38	37	Gallium(III) oxide	Metal	Negligible concentrations with minimal impact on the material's characteristics.
19	NiO	0	0.0058	0	28	Nickel(II) oxide	Metal	Low concentrations, particularly in CA, with limited impact on material properties.
20	Cl	0.01189	0.00729	18	11	Chlorine	Nonmetal	Both samples contain chlorine in trace amounts, likely with minimal influence.
21	ZrO2	0.194	0.0492	305	102	Zirconium dioxide	Metal	Higher ZrO2 in CA may contribute to enhanced properties, including strength and durability.
22	Ta2O5	0.0102	0.01175	11	13	Tantalum(V) oxide	Metal	Similar concentrations with limited impact on material characteristics.
23	Br	0	0	0	0	Bromine	Nonmetal	Both samples show no significant presence of bromine.
24	SrO	1.002	2.589	67	193	Strontium oxide	Metal	Higher SrO in RAP, indicating potential differences in material properties.
25	Nb2O5	0.1339	0.1369	10	12	Niobium(V) oxide	Metal	Similar concentrations with limited impact on material characteristics.
26	Bi2O3	0.0466	0.04707	1	1	Bismuth(III) oxide	Metal	Comparable concentrations with minimal influence on the material's characteristics.
27	Sb2O3	1	0.53	0	1	Antimony(III) oxide	Metalloid	Higher Sb2O3 in CA, potentially impacting material properties.
28	Co3O4	0	0	0	0	Cobalt(II,III) oxide	Metal	Both samples show no significant presence of cobalt oxide.
29	CdO	0	0	0	0	Cadmium oxide	Metal	Negligible concentrations of cadmium oxide in both samples.
30	HfO2	0.001611	0.001074	14	8	Hafnium dioxide	Metal	Similar concentrations with limited impact on material characteristics.
31	Ag2O	0	0	0	0	Silver(I) oxide	Metal	Both samples show no significant presence of silver oxide.
32	CeO2	0.1091	0.0617	117	66	Cerium(IV) oxide	Metal	Slightly higher CeO2 in CA, indicating potential variations in material characteristics.
33	BaO	0.4823	1	71	0	Barium oxide	Metal	Higher BaO in RAP, suggesting potential differences in the material's properties.
34	Au	[0.00023]	[0.00027]	0	0	Gold	Metal	Minimal concentrations of gold in both samples, likely with negligible influence.
35	WO3	[-0.06000]	[-0.06000]	9	11	Tungsten(VI) oxide	Metal	Negative concentrations in both samples, potentially an analytical

								artifact or indicating absence.
36	MoO3	[-0.0080]	[-0]	2	0	Molybdenum(VI) oxide	Metal	Negative concentrations in both samples, potentially an analytical artifact or indicating absence.
37	La2O3	0	0	0	0	Lanthanum(III) oxide	Metal	Both samples show no significant presence of lanthanum oxide.
38	ThO2	0	0	0	0	Thorium dioxide	Metal	Negligible concentrations of thorium oxide in both samples.
39	SnO2	0.28	0	3	0	Tin(IV) oxide	Metal	Higher SnO2 in CA, indicating potential variations in material characteristics.

4.4 Experimental Design for Replacement of Reclaimed Asphalt Pavement (RAP) with Coarse Aggregates at Different Percentages and Testing Durations.

The experimental methodology involved the partial replacement of coarse aggregates with RAP across five different proportions: 0%, 25%, 50%, 75%, and 100%. To ensure the robustness and consistency of the findings, three mixtures were prepared for each proportion. Testing was conducted over two distinct timeframes: 7 days and 28 days. Compressive strength tests were executed on standardized concrete cubes measuring 150 x 150 x 150mm. Additionally, flexural strength and split tensile strength tests were meticulously performed.

4.5 Justification for the use of this design

Employing a 25% increment in mix percentages, ranging from 0% to 100% for the replacement of Reclaimed Asphalt Pavement (RAP) with natural aggregates, was a deliberate and advantageous strategy. Primarily, this incrementation facilitates a seamless transition and systematic evaluation of how RAP content influences concrete properties. By adjusting the RAP content in 25% increments, researchers can discern gradual variations in concrete characteristics, enhancing comprehension of the relationship between RAP content and concrete performance.

Moreover, the 25% increment strikes a balance between precision and efficiency. It offers a substantial step size to capture notable shifts in concrete properties while avoiding excessive testing and resource allocation. Furthermore, the 25% increment aligns with practical considerations in construction and pavement engineering. It mirrors standard practices where RAP content adjustments are made in increments of 25% or similar proportions during mix design and production processes, ensuring the relevance and applicability of research outcomes to real-world applications. In essence, adopting a 25% increment in mix percentages for evaluating RAP replacement achieves a harmonious blend of detail and practicality, enabling comprehensive investigations while upholding efficiency and relevance to industry standards.

4.6 Discussion of Results for Compressive Strength

The findings indicate a general increase in compressive strength across the concrete mixes with longer curing periods, evident from higher average values observed at 28 days compared to 7 days. This trend aligns with expectations, considering concrete's gradual strength development due to hydration processes.

Notably, mixtures with 50% RAP replacement demonstrated the highest average compressive strength both at 7 days (18.40 N/mm^2) and 28 days (26.25 N/mm^2), indicating an optimal balance between RAP content and concrete performance. Moreover, mixtures with 25% and 100% RAP replacement also exhibited relatively high compressive strength values, implying favorable outcomes even with moderate levels of RAP incorporation. Consequently, based on the 28-day strength, the optimal compressive strength is achieved at 50% RAP. This assessment is summarized in Table 2 and illustrated in Figure 10a illustrates a Compression Machine for testing the compressive strength of concrete cubes by applying controlled force until fracture. Figure 10b displays a concrete cube specimen securely positioned between compression plates before testing. In Figure 10c, a crushed concrete cube post-testing reveals internal structure, offering insights into mechanical properties, notably compressive strength.

Figure 10a: Compression Machine

Figure 10b: Cube in testing

Figure 10c: Crushed Cube

Table 2: Experimental Results for Compressive Strength

Mix Percentage	RAP (%)	Natural Coarse Aggregates (%)	Number of Samples	Average of Compressive Strength at 7 Days(N/mm2)	Average of Compressive Strength at 28 Days(N/mm2)
0%	0	100	3	17.24	24.24
25%	25	75	3	18.30	25.20
50%	50	50	3	18.40	26.25
75%	75	25	3	17.01	26.05
100%	100	0	3	17.03	25.95

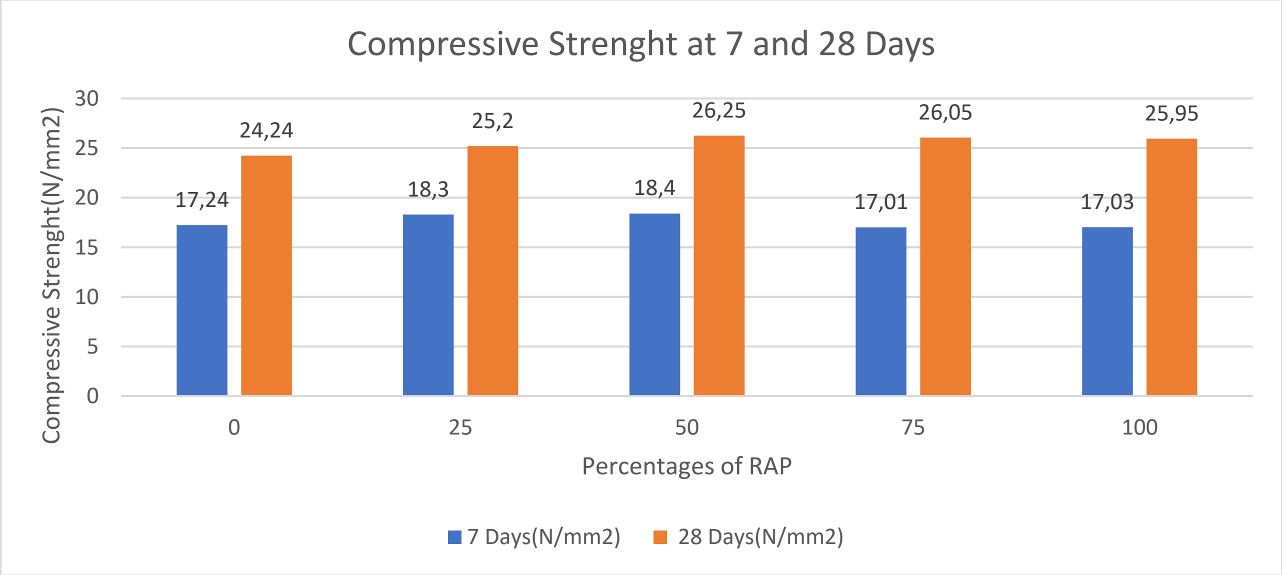


Figure 11: Compressive Strength at 7 and 28 Days

4.7. Discussion of Results for Split Tensile Strength

Table 3, supplemented by Figure 11 below, illustrates the experimental findings regarding the split tensile strength of concrete mixtures with varying percentages of Reclaimed Asphalt Pavement (RAP) and natural coarse aggregates.At 7 days, the mixture with 50% RAP replacement demonstrated the highest average split tensile strength (1.85 N/mm²), closely followed by mixtures with 75% RAP replacement (1.75 N/mm²) and 25% RAP replacement (1.70 N/mm²). Slightly lower average split tensile strengths at 7 days were observed for mixtures with 0% and 100% RAP replacement (1.20 N/mm² and 1.70 N/mm² respectively).

Similarly, at 28 days, the mixture with 75% RAP replacement exhibited the highest average split tensile strength (3.05 N/mm²), followed by the mixture with 50% RAP replacement (2.65 N/mm²) and 25% RAP replacement (2.25 N/mm²). Mixtures with 0% and 100% RAP replacement showed lower average split tensile strengths at 28 days (2.05 N/mm² and 2.75 N/mm² respectively). These results suggest that the optimum split tensile strength is achieved with 75% RAP replacement, as it consistently displayed the highest values at 28 days, indicating superior performance compared to other mixtures.Figure 12a and Figure 12b showcase crushed cylindrical samples resulting from testing. These images provide visual evidence of the specimens' behavior under applied stress, offering insights into their mechanical properties and failure mechanisms.

Figure 12a: Crushed Cylindrical samples

Figure 12b: Crushed Cylindrical samples

Table 3: Experimental Results for Split Tensile Strength

Mix Percentage	**RAP (%)**	**Natural Coarse Aggregates (%)**	**Number of Samples**	**Average of Split Tensile Strength at 7 Days(N/mm2)**	**Average of Split Tensile Strength at 28 Days(N/mm2)**
0%	0	100	3	1.20	2.05
25%	25	75	3	1.70	2.25
50%	50	50	3	1.85	2.65
75%	75	25	3	1.75	3.05
100%	100	0	3	1.70	2.75

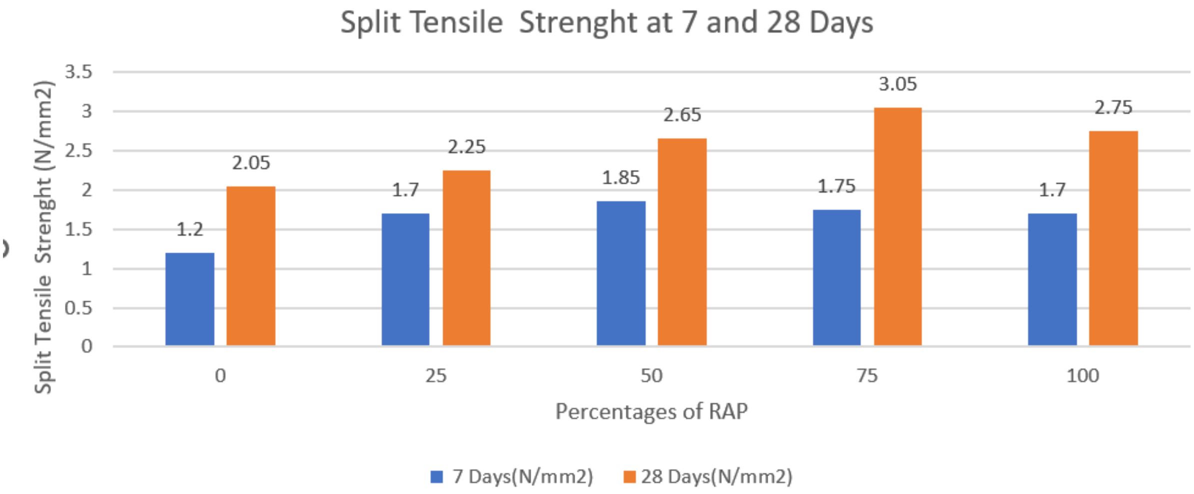


Figure 13: Split Tensile Strength at 7 and 28 Days

4.8 Discussion of Results for Flexural Strength

Table 4 provides the experimental findings for the flexural strength of concrete mixtures incorporating various percentages of Reclaimed Asphalt Pavement (RAP) and natural coarse aggregates.

At 7 days, the mixture with 50% RAP replacement demonstrated the highest average flexural strength (1.90 N/mm²), closely followed by mixtures with 75% RAP replacement (1.75 N/mm²) and 100% RAP replacement (1.85 N/mm²). Slightly lower average flexural strengths at 7 days were observed for mixtures with 0% and 25% RAP replacement (1.10 N/mm² and 1.35 N/mm² respectively).

At 28 days, the mixture with 75% RAP replacement exhibited the highest average flexural strength (2.45 N/mm²). Conversely, mixtures with 0% and 25% RAP replacement displayed lower average flexural strengths at 28 days (2.00 N/mm² and 2.05 N/mm² respectively). Figure 13 depicts the split tensile strength of concrete at 7 and 28 days for various levels of Reclaimed Asphalt Pavement (RAP) replacement. The figure reveals that the split tensile strength increases between 7 and 28 days for all concrete mixtures, reflecting the gradual development of concrete's tensile properties over time. Figure 15 illustrates the flexural strength of concrete at 7 and 28 days for different levels of Reclaimed Asphalt Pavement (RAP) replacement. The results show a general increase in flexural strength from 7 to 28 days across all mixtures, indicating the expected development of concrete strength over time.

Consistently, the mixture with 75% RAP replacement showed the highest average flexural strength values at 28 days (2.45 N/mm²), indicating its superior performance compared to other mixtures in this experimental setup. Therefore, the optimal flexural strength is achieved with 75% RAP replacement. Figure 14a displays a flexural testing machine used to assess the flexural strength of materials, while Figure 14b shows a beam specimen being tested in the machine.

Figure 14a: Flexural testing Machine

Figure 14b: Beam during testing

Table 4: Experimental Results for Flexural Strength

Mix Percentage	**RAP (%)**	**Natural Coarse Aggregates (%)**	**Number of Samples**	**Average of Flexural Strength at 7 Days(N/mm2)**	**Average of Flexural Strength at 28 Days(N/mm2)**
0%	0	100	3	1.10	2.00
25%	25	75	3	1.35	2.05
50%	50	50	3	1.90	2.25
75%	75	25	3	1.75	2.45
100%	100	0	3	1.85	2.40

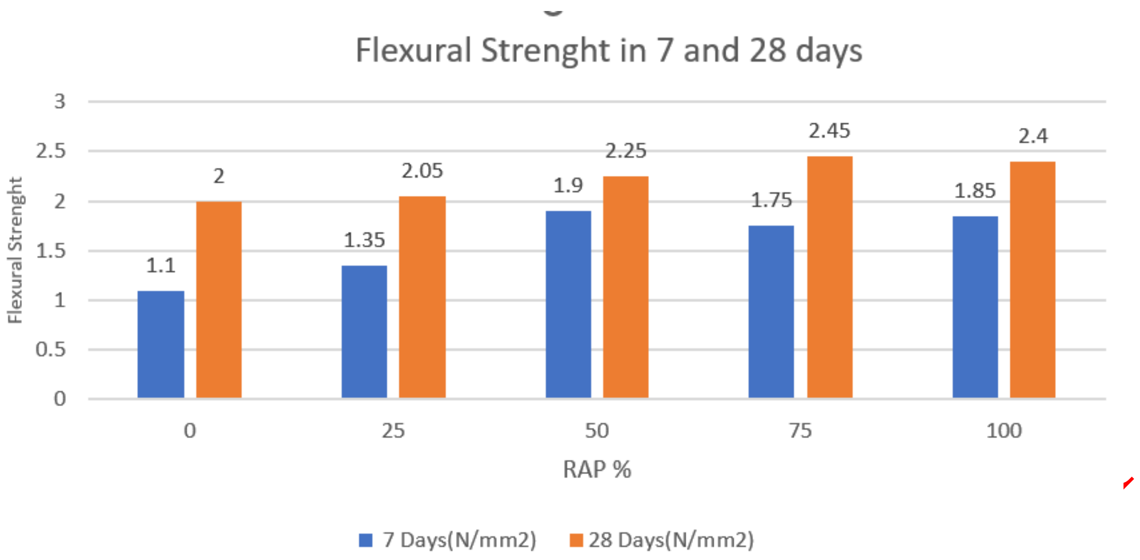


Figure 15: Flexural Strength at 7 and 28 Days

4.9 Challenges and Limitations

The study encounters methodological limitations that could impact the comprehensive understanding of oxide concentrations in coarse aggregates (CA) and recycled asphalt pavement (RAP). Challenges include the potential bias in sample selection, leading to questions about the representativeness of the findings across different sources. Discrepancies in analytical techniques and equipment calibration across laboratories could introduce inconsistencies, and the study's exclusive focus on oxide concentrations overlooks other crucial factors influencing construction materials. The absence of detailed information on the specific sources and processing methods of CA and RAP samples further limits the study's depth. Acknowledging these limitations is essential for interpreting the findings judiciously, and future research should address these challenges to advance the understanding of recycled materials' impact on construction.

5.0 CONCLUSION

5.1 Summary of Findings

The comparative analysis of oxide concentrations in coarse aggregates (CA) and recycled asphalt pavement (RAP) revealed nuanced differences in the chemical composition of these materials. Key findings include variations in concentrations of essential oxides such as silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and calcium oxide (CaO). Silicon dioxide, a major component in aggregates, exhibited a notable decrease in RAP compared to CA, potentially influencing concrete strength and durability. Additionally, certain oxides, including copper(II) oxide (CuO) and zinc oxide (ZnO), displayed differences between CA and RAP, indicating potential implications for material properties.The study delved into the mechanical properties of concrete blends incorporating Reclaimed Asphalt Pavement (RAP) alongside natural coarse aggregates, offering valuable insights into their behavior. It revealed a consistent trend of increasing compressive strength with longer curing periods, emphasizing the crucial role of hydration processes in enhancing concrete durability. Mixtures with a 50% RAP replacement demonstrated the highest average compressive strength at both 7 and 28 days, indicating an optimal balance between RAP content and concrete performance. Similarly, the evaluation of split tensile strength showcased the superior performance of mixtures containing 75% RAP replacement, highlighting their ability to enhance structural integrity. Furthermore, the analysis of flexural strength reinforced the effectiveness of RAP integration, with blends featuring 75% RAP replacement showing the highest average flexural strength values.

5.2 Concluding Remarks

In conclusion, the study provides valuable insights into the chemical composition of coarse aggregates and recycled asphalt pavement, shedding light on their potential impact on construction materials. The observed variations in oxide concentrations highlight the importance of careful consideration when incorporating recycled materials into construction projects. The findings contribute to the ongoing discourse on sustainable construction practices and offer a foundation for further research on optimizing the use of recycled materials in the development of robust and environmentally friendly infrastructure. As construction industries continue to prioritize sustainability, understanding the intricacies of material composition becomes imperative for informed decision-making and the advancement of eco-friendly construction practices. the experimental investigation into the mechanical properties of concrete mixtures incorporating Reclaimed Asphalt Pavement (RAP) and natural coarse aggregates yielded valuable insights into their performance. The study revealed a consistent trend of increased compressive strength with longer curing durations, emphasizing the importance of hydration processes in enhancing concrete strength. Mixtures with 50% RAP replacement exhibited the highest average compressive strength at both 7 and 28 days, suggesting an optimal balance between RAP content and concrete performance. Similarly, the split tensile strength analysis indicated superior performance of mixtures with 75% RAP replacement, showcasing their potential for enhancing structural integrity. Flexural strength results further supported the efficacy of incorporating RAP, with mixtures containing 75% RAP replacement displaying the highest average flexural strength values.

AUTHORS' CONTRIBUTIONS

Michael Tiza: Performed the experiments and drafted the article.

Fidelis Okafor: Reviewed the drafted copy, supervised the performance of the experiments and analysed the results.

Jonah Agunwamba: Conceptualized the article, reviewed, supervised the entire process of experiments and analysed the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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