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EXPLORING THE POTENTIAL OF RED ASH AND MARBLE CHIPS AS ALTERNATIVES IN BASE COURSE MATERIAL VIA BLENDING WITH CRUSHED STONE AGGREGATE

Dessalegn Getahun, Anteneh Geremew and Melka Amensa*
Faculty of Civil and Environmental Engineering, Jimma University, P.O. BOX 378, Jimma, Ethiopia

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*Corresponding author's email: melame7@yahoo.com
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Abstract — Despite its abundance, red ash has compaction issues owing to its lightweight, rough circular surface, and high porosity. The usage of conventional base course materials across the country incurs shipping expenses and takes time, slowing down projects because they are only widely available in limited areas across the country. In this study, non-probably sampling approach was used to examine the potential for employing red ash and marble chips as an alternative base course material by mixing them with crushed stone aggregate (CSA). In order to accomplish the goal of this study, an experimental test was conducted via trial and error, focusing on the mechanical stabilization of red ash and marble chips. Their physical characteristics were subsequently assessed through laboratory testing. In the laboratory, nine (9) samples of red ash and marble chips blended with CSA in varying percentages (0, 5, 10, 15, 20, 25, and 30 percent) were examined. The laboratory test results showed that 100% red ash and marble chips gave; CBR, SG, AIV, ACV, LAA, FI, EI, water absorption, and soundness: 55.4%, 2.38%, 18.20%, 26.34%, 19.69%, 5.59%, 12.09%, 2.5% and 13.80 and 83.6%, 2.63%, 19.70%, 26.41%, 19.75%, 23.2%, 16.9%, 1.24% and 12.22 respectively. Several of these test results align with the Ethiopian Road Authority (ERA) standard specifications; however, the findings from the CBR, water absorption, and soundness tests do not. Thus, mechanical stabilization was employed to improve the samples' physical characteristics. Experimental results are obtained by mixing 20% red ash, 20% marble chips, and 60% CSA. The values for CBR, SG, AIV, ACV, LAA, FI, EI, water absorption, and soundness are 102.5%, 2.55, 14.23%, 19.84%, 7.92%, 18.61%, 20.77%, 0.83%, and 7.38, respectively. The CBR, water absorption, and soundness characteristics all meet the necessary ERA standard specifications for crushed weathered rock (GB2) and natural coarsely graded granular materials (GB3) at this particular proportion. Hence, it is recommended to incorporate red ash up to 20% and marble chips up to 20% by weight, alongside 60% CSA, for constructing road base courses, particularly when these materials are reasonably accessible from construction sites and are widely available in the area.

***Keywords*:** base course, red ash, marble chip, CSA, CBR, standard specification

1.0 INTRODUCTION

The growth of the transportation sector and the massive increase in the number of vehicles on the road have driven the exploitation of every practicable resource, leading to the development of better and longer-lasting roads. When conventional raw materials like bitumen, crushed aggregates, and unbound aggregate mixtures began to deplete in the 1980s, the use of unconventional construction materials in road construction commenced [1]. The depletion of natural resources during the production of aggregate materials has severely disrupted the environment [2]. The alarming rate of increasing waste generation underscores the efforts to explore the potential use of diverse byproducts in road development [3]. Some of the most frequently used recycling materials include plastic wastes, used tires, foundry sand, bottom and fly ashes, oil sand, marble dust, recycled concrete aggregates, recovered asphalt pavement, and steel slag. There has been extensive research in this direction [4][5], with ongoing studies to find more effective ways to use these recycled materials. Waste management remains a significant challenge for governmental institutions and transportation legislation authorities in many areas of the world. Many international corporations contribute to preserving natural resources and protecting the environment by using feasible recycled materials in the building sector [6].

According to traditional specifications, a non-conventional material lacks the necessary qualities [7]. The inclusion of secondary materials and waste byproducts in road construction has become urgently necessary due to the constant demand for aggregate materials in the industry, the scarcity of materials of acceptable quality, and the need to preserve natural resources. Numerous recycled waste materials have been used in projects worldwide, demonstrating the potential for both financial savings and environmental protection. Road long-term performance depend heavily on the properties of the materials used in the structure's compositions. Therefore, understanding how these materials behave in different situations, whether used alone or in combination with other materials to form a road pavement structure, is crucial. The responses to the enormous demand for alternatives to natural materials in road construction reflect a greater concern on sustainability from an economic and environmental perspective [8].

The Ethiopian government has implemented various reforms, including structural adjustment programs, agricultural marketing, private sector development, and associated programs aimed at reducing poverty. Successful program implementation requires an effective infrastructure system, with road traffic playing a key role in creating a network of various infrastructures [9]. Roads have significantly contributed to the economic, cultural, and social development of people, facilitating transportation across the country. The Ethiopian government allocates significant resources to highway construction, contributing to the economic development of the nation. With the daily rise in the demand for coarse aggregate, the Ethiopian road network is crucial to the country's economy. To maintain a high level of service, the network must adhere to appropriate standards for design, construction, and maintenance. The right choice of preservation strategies becomes increasingly crucial as the road network expands. For developing nations like Ethiopia, the use of more affordable building materials without sacrificing performance is essential. The ongoing rise in the price of traditional building materials prompted the researcher to investigate potential substitutes to reduce overall construction costs without compromising safety. The study aimed to determine whether red ash and marble chips can be used in the base course material by blending them with crushed stone aggregate. CSA is one of the most adaptable and frequently used materials in the global road construction sector [10].

Basalt is the predominant rock used for aggregate production in Ethiopia. The most widely used local coarse aggregates belong to the igneous rock family known as red ash or pumice, made from light volcanic ash and normal-weight crushed basaltic stone. Base courses in flexible pavement structures that must handle heavy traffic demand careful consideration in their design and construction. Rough pavements or failures may occur if the bases are not compacted to match the amount of traffic generated. Red ash and marble chips base courses, when properly placed and compacted, produce a strong and durable pavement base course. They are proportioned mixtures of red ash, marble chips, and crushed stone aggregate. Red ash and marble dust could replace some traditional crushed stone aggregate in road projects, reducing the cost of construction, provided that the strength and stability of the entire compacted mass in the base course layer of flexible pavement are not significantly weakened.

The objective of this study is to examine the viability of using red ash and marble chips in place of some crushed stone aggregate in the base course layer construction. This involves determining their engineering properties, the optimum amount to be used in the mix, and comparing this with Ethiopian road authority standards. Pumice and red ash, two lightweight aggregates, and basalt, a heavier aggregate, also have different production processes. Lightweight aggregates are generated from quarries by simple digging or bulldozing due to their soft nature. The sizes produced primarily depend on the method employed, whether it be digging or bulldozing [11]. Natural gravel, while a cheap alternative to more expensive materials like crushed stone, does not always meet the standards for bases. To gain considerable economic and environmental benefits, the qualities of locally accessible materials, such as natural cinder gravels, can be improved by stabilizing the processes. However, these options are frequently not locally available, and transporting large quantities in big vehicles is expensive. Natural cinder gravels are pyroclastic sediments connected to recent volcanic activity, ranging in color from red, brown, grey, to black. The particle sizes range from sand and silt sizes to irregularly shaped lumps with a diameter of 0.5 m. Cinder gravel is porous, has a rough surface, and is lightweight [12].

Cinder gravel has been used in various engineering projects in Ethiopia on low-traffic highways as a sub-base and base course. Investigations involving sampling, laboratory analysis, field compaction tests, and full-scale application tests have shown that even when subjected to increased traffic loads of up to three million ESAs, trial stretches of roads continue to perform satisfactorily. When paired with fine-grained soils, volcanic ash, and lime stabilization, cinder gravel is suitable as a foundation course material [13]. The reuse of waste materials is the primary method for reducing the demand for natural raw materials, offering both economic and environmental benefits.

1.1. Statement of Problem

Large quantities of raw resources have been exploited due to the need for infrastructure brought on by population growth, rapid urbanization, and industrialization worldwide. The use of aggregates and other raw materials in road construction is widespread. However, the materials like red ash and marble chips, which are unconventional for road-making, need improvement. This is particularly crucial given the increasing frequency of road damage faced by the Ethiopian Road Authority (ERA), draining scarce resources to sustain repairs. Utilizing cost-effective materials is essential for efficient road project management [10].

Red ash and marble chips, being uncommon in base and secondary courses, can significantly lower the cost of building highways. In road infrastructure projects, the quality of the base course material and the distribution of its grains are paramount. If sufficient base course material is not available near the construction site, road construction may face delays or increased costs. Additionally, using subgrade materials in these circumstances may adversely affect the road's long-term quality and durability, resulting in substantial losses. Thus, improving material quality is crucial for road construction projects to ensure compliance with necessary cost and quality standards [14][15]. The primary objective of this research is to address the challenge of base course material scarcity (CSA) in the study area.

Marble chips, which are a type of industrial waste during the cutting of marble stone for construction purposes, offer a sustainable solution. By utilizing marble chips as the coarse aggregate in the base course, the demand for CSA is reduced. This not only eliminates the need for natural aggregate extraction, a resource-intensive and environmentally hazardous process, but also reduces the disposal of industrial waste and the land required for resource extraction. Previous research has explored the use of marble waste and red ash with CSA, revealing their benefits. This investigation focuses on blending these materials in varying proportions, aiming to understand the engineering properties of individual and combined materials to create a base course that complies with ERA and AASHTO standard specifications. Instead of conventional aggregate, utilizing leftover marble has been proven to be a viable alternative [2][4][16].

2.0 MATERIALS AND METHODS

2.1. Material Required

Non-probabilistic purposive sampling techniques were employed to gather the materials required for this research. Marble chips aggregate, red ash, and crushed stone aggregate (CSA) were selected as the primary materials. Red ash samples were purposively collected from Woliso district based on material availability, while marble chips were sourced from the Asko Marble factory, and crushed stone aggregates were obtained from the Jimma aggregate crusher plant.

The materials are suitable for road base construction, and the following equipment was utilized: sieve, crushed aggregate, balance, oven, dish, water, ponding surface, impact testing machine, compression testing machine, abrasion machine, brushes, and sample containers.

2.2. Study Design

In this study, an experimental comparative study design technique was employed on nine samples of materials by performing minimum mass of sample materials required for laboratory tests in accordance with AASHTO T-86. These samples were prepared for laboratory test to characterize individual and blended materials to see their effect as illustrated in Figure 1.

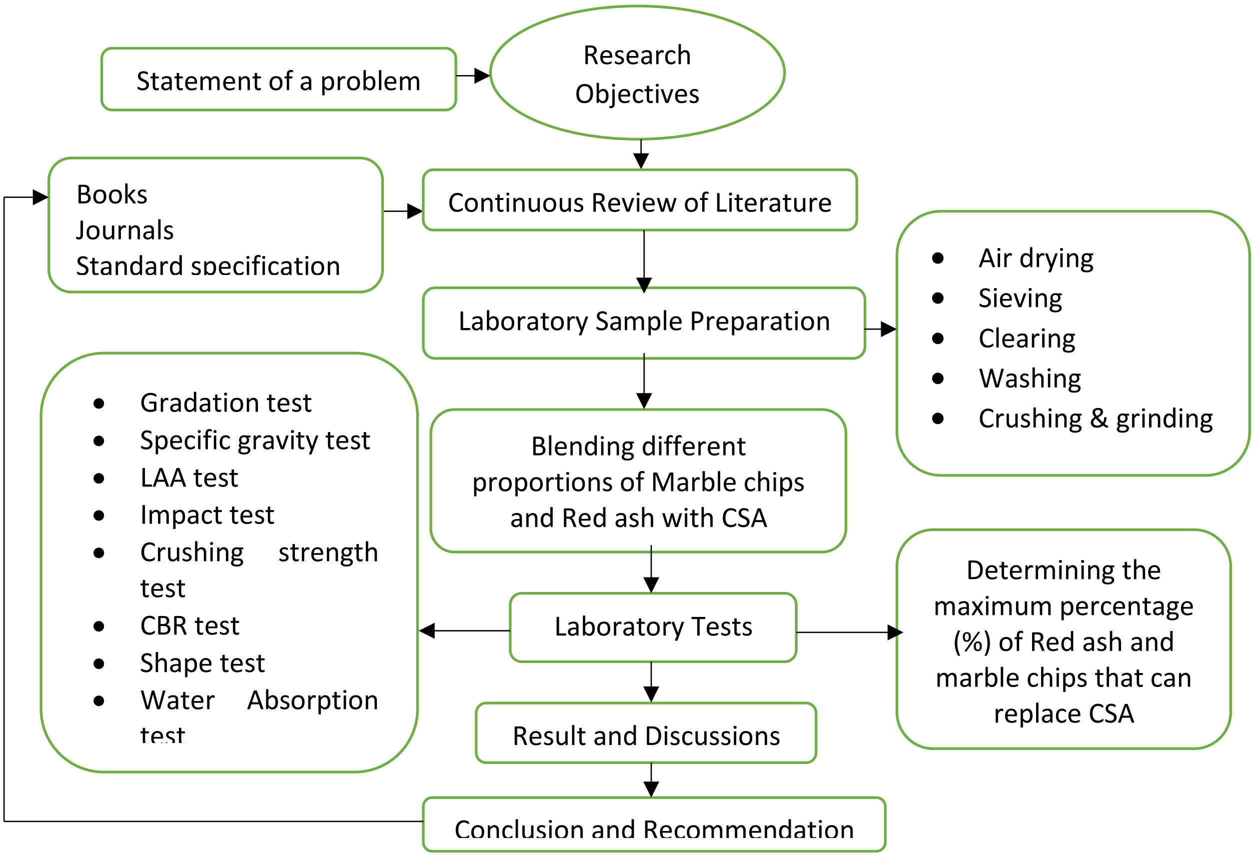

Figure 1 Flow chart showing study design

2.3. Sample Preparation Procedures

The representative samples were collected from the identified sources by adopting AASHTO T-2 recommendation and a mechanical splitter method was used in order to collect a representative sample for all tests. The details of this procedure can be referred to in AASHTO T – 248. In this investigation, the proposed mix design was prepared for a detailed investigation to achieve the objective of the study as illustrated in Table 1.

Table 1 Mix Design sample list

List of samples	Percent of mix (ratio)
First sample	100% Red ash (RA)
Second sample	100% (CSA)
Third sample	100% Marble chips (MC)
1st mix	5% RA + 5% MC+ 90%CSA
2nd mix	10% RA + 10% MC+ 80%CSA
3rd mix	15% RA + 15% MC+ 70%CSA
4th mix	20% RA + 20% MC+ 60%CSA
5th mix	25% RA + 25% MC+ 50%CSA
6th mix	30% RA + 30% MC+ 40%CSA

2.4. Standards and Specifications

The laboratory tests conducted in this experimental study are conducted as per Table 2 for further comparison with the standard specification of the country.

Table 2 Standards and Specification for this Study

S/N	Test Type	Reference Codes
1	A sieve analysis	AASHTO T-27
2	Water Absorption	BS EN 1097-6
3	Specific Gravity	ASHTO T 85 /ASTM methods are C127/ for coarse
4	Flakiness Index	BS EN 933-3
5	Elongation Index	BS EN 933-3
6	Aggregate Crushing Value (ACV)	BS 812: Part 110:1990
7	Aggregate Impact value (AIV)	ASTM D5874
8	Ten Percent Fines Value Test (TFV)	BS: 2386 (Part IV)-1963
9	Los Angeles Abrasion (LAA)	AASHTO T 96-94
10	Soundness of Aggregate	AASHTO T 104
11	California Bearing Ratio (CBR)	ASTM, AASHTO, British Standards (BS)

3.0 RESULTS AND DISCUSSIONS

3.1. Soil Classification

Marble chips and red ash under this study were classed as granular materials according to AASHTO's soil classification system since the percentage passed sieve #200 was less than 35% and additional categorization was conducted because granular material is divided into subgroups A-1, A-3, and A-2. This was accomplished by ensuring that each sample passes sieve sizes #10, #40, and #200 in addition to the PI value. Since less than 15% of particles pass 0.075 mm, less than 30% pass the no. 40 sieve and less than 50% passing the no. 10 sieve with PI 6, all materials were consequently classified as A-1-a type of soils. A-1-a soil was preferred for use as highway-building soil according to the AASHTO categorization system and a detailed soil classification is illustrated in Table 3.

Table 3 Classification of Soil

	Appropriate Sample Composition selected for this study								
Parameters Used for Classification	**Red ash (RA)**	**CSA**	**Marble chips (MC)**	**5%RA+5%MC+90%CSA**	**10%RA+10%MC+80%CSA**	**15%RA+15%MC+70%CSA**	**20%RA+20%MC+60%CSA**	**25%RA+25%MC+50%CSA**	**30%RA+30%MC+40%CSA**
D_{10}(mm)	0.18	0.2	0.25	0.19	0.21	0.22	0.2	0.18	0.15
D_{30}(mm)	2.5	3.1	3.2	2.7	2.5	3	2.6	3.3	3.5
D_{60}(mm)	10.5	14.3	15	15	12	14	16	13	11
Coefficient of Uniformity, Cu	58.33	91.5	60.00	78.94	57.14	63.64	80.00	86.67	73.33
Coefficient of Curvature, Cc	3.31	2.54	2.73	2.56	2.48	2.92	2.11	4.65	7.42
Gravel Content, %	53.2	85.3	75.5	88.8	82.5	75.7	72.8	63.4	57.8
Sand Content, %	28.7	12.5	18.4	15.7	19.3	21.5	25	33	41.2
Fine Content, %	11	1.52	5.6	3.2	3.7	4.8	5.3	8.9	14.6
AASHTO Classification	A-1-a								
USCS Classification	GW								

3.2. CSA, Red ash, Marble Chips Aggregate and Their Blend Gradation

To maintain the required particle size and quantity, the gradation (Particle Size Distribution) of a particular pavement aggregate must be regularly checked. In order to ascertain the percentage of gravel, sand, and fine in the CSA, marble chips, and red ash samples, the analysis of particle size distribution was used. The results are shown in Figure 2 as follows.

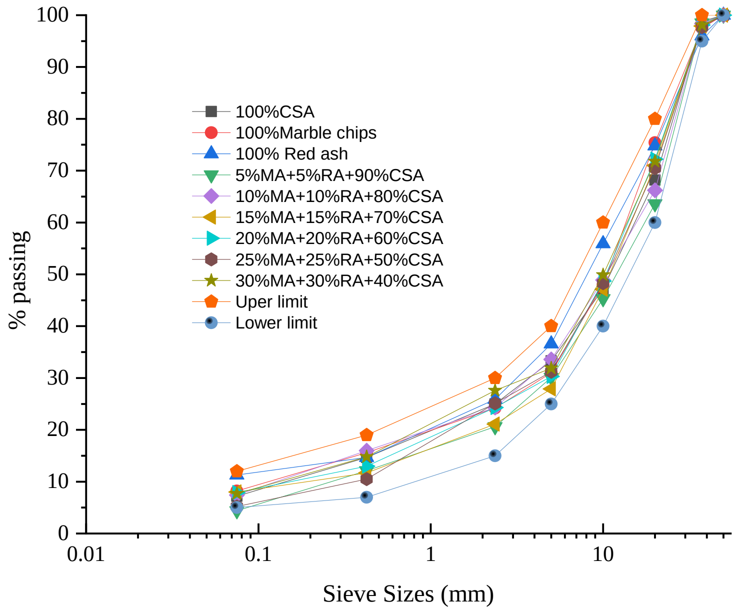

Figure 2 CSA, Red ash, marble chips aggregate, and their blend Gradation

3.3. Effect of Flakiness and Elongation Index

The usage of flaky particles in road construction is not recommended. This is due to the fact that the flaky flat particles may break down more readily when the load acts along their thin axis, or their axis of minimal moment of inertia. Flakiness Index of aggregates used in road construction should be less than 30% and recommended value for elongation index was 10% to 35% as per ERA and BS standard specification. The results of laboratory tests on flakiness and elongation indexes for neat CSA, marble chips, red ash, and blended materials revealed that the highest FI value of 23.2% was recorded for neat marble chips, while neat red ash yielded a value of 5.59%, both falling within the acceptable limits. Similarly, as depicted in Table 4, the elongation index ranged between 12.09% and 25.5%, remaining within the acceptable range.

Table 4 Flakiness and Elongation Index of samples

Material Type	Flakiness and Elongation Index Value		BS 812 standard
	FI (%)	EI (%)	FI<30%
CSA	15.3	15.84	EI 10% to 35%
Marble chips	23.2	16.9	
Red ash	5.59	12.09	
5%MA+5%RA+90%CSA	19.42	22.60	
10%MA+10%RA+80%CSA	19.9	23.33	
15%MA+15%RA+70%CSA	18.58	20.73	
20%MA+20%RA+60%CSA	18.61	20.77	
25%MA+25%RA+50%CSA	22.06	24.65	
30%MA+30%RA+40%CSA	22.83	25.50	

3.4. Aggregate Crushing and Impact Value

The two compulsory mechanical qualities of aggregate are sufficient resistance to surface abrasion from traffic and excellent resistance to crushing under the roller during construction. From the test result on table 5 , it can be seen that the neat and blended materials have ACV within the permissible range of less than 30% as per BS 812, even though ACV increases from 12.77% to 25.92% for increment of MA and RA from 5% to 30% which is due to less capability of marble chips and red ash to crushing when compared to CSA. Similarly, aggregates should be tough, which means they must be able to resist sudden load acting on them. Table 5 shows that AIV when blending materials gradually increase from 8.5% to 16.8% up on addition of 5% to 30% of MA and RA due to less toughness of marble chips and red ash. Hence it can be seen that all the neat CSA, marble chips, red ash and their blend have proved good resistance to abrasion, crushing and sudden load as per BS and ERA specification.

Table 5 Aggregate Crushing and Impact Value

Material	ACV (%)	AIV (%)	ERA Standard
CSA	5.02	6.90	ACV < 30 %
Marble chips	26.41	19.70	AIV < 30 %
Red ash	26.34	18.20	
5%MA+5%RA+90%CSA	12.77	8.50	
10%MA+10%RA+80%CSA	16.25	12.50	
15%MA+15%RA+70%CSA	16.92	13.30	
20%MA+20%RA+60%CSA	19.84	14.30	
25%MA+25%RA+50%CSA	21.54	15.60	
30%MA+30%RA+40%CSA	25.92	16.50	

3.5. Los Angeles Abrasion Test

When evaluating the hardness property of all the samples including CSA, marble chips, red ash, and a blend of different proportions of these materials, the percentage of wear due to relative rubbing action between the samples and steel balls was determined. The results are presented in Table 6. The results of the material test shows that the neat CSA, MA, RA and blend of CSA with marble chips and red ash samples for LAAV were within the allowable ERA standard specification for base course materials requirement with increment in LAAV from 7.32% to 14.52% for increased percentage of MA and RA from 5% to 30%. Significant change occurs in resistance against abrasion and impact with the increase of marble chips and red ash in the mixture beyond 20%

Table 6 Los Angeles Abrasion Value

% of MA & RA added for LAAV test	CSA	Marble chips	Red ash	5	10	15	20	25	30
LAAV (%)	7	19.75	19.68	7.32	7.62	7.84	7.92	11.94	14.52
Specification	LAAV < 45 %								

3.6. Specific Gravity and Water Absorption

Specific gravity water absorption tests offer valuable insights into the strength, quality, and water-holding capacity of the materials. As shown in table 7, average specific gravity for different types of marble chips and red ash was less than CSA. The water absorption of CSA was also much less than marble chips and red ash, this may be due to the smoothness and low porosity of CSA. From these results, it is evident that all neat and blended samples, except for neat marble chips and red ash, along with their blend to crushed stone aggregate exceeding 30%, exhibit a specific gravity that meets the minimum requirement of 2.65 for GB1 according to ERA specifications. The test results also demonstrate that specific gravity increases to some extent with the increment of MA and RA. Additionally, it is observed that water absorption value decreases as the percentage of MA and RA increases, albeit only up to 20%.

Table 7 Specific Gravity and Water Absorption for Samples

Material list	**Average Specific Gravity**		**Average Absorption (%)**	**Standard Specification**
	The Bulk (SSD)	**Apparent SG**		
CSA	3.02	3.11	0.96	Water absorption < 2% Specific gravity <2.65
Marble chips	2.63	2.72	1.24	
Red ash	2.38	2.54	2.5	
5%MA+5%RA+90%CSA	2.76	2.96	2.54	
10%MA+10%RA+80%CSA	2.81	3.03	2.54	
15%MA+15%RA+70%CSA	2.87	2.94	0.83	
20%MA+20%RA+60%CSA	2.81	2.87	0.83	
25%MA+25%RA+50%CSA	2.68	2.85	2.26	
30%MA+30%RA+40%CSA	2.53	2.69	2.26	

3.7. Moisture Density Relationship of Blended CSA, Marble Chips and Red Ash

The blending of marble chips and red ash with pure aggregate has shown certain trends concerning the material's MDD and OMC. As observed from Table 8, the OMC of the mixtures increases from 4.15 to 4.75 with the increasing percentages of marble chips and red ash from 5% to 25%. Notably, these values remain higher than those of CSA and marble chips but lower than that of red ash. This may be due to the smoothness and water resistance capacity of marble chips and high absorption characteristics of red ash. The results show that the MDD of the mixture containing marble chips and red ash is slightly lower than that of neat CSA. Specifically, the MDD decreases from 1.99 for neat CSA to 1.77 as the percentage of marble chips and red ash increases from 5% to 25% in the mixture. This decline can be attributed to weak bonding between the components.

Table 8 Effect of CWA on MDD and OMC values of CSA

Material list	**OMC**	**MMD**
CSA	4.32	1.99
Marble chips	3.79	2.15
Red ash	11.61	1.50
5%MA+5%RA+90%CSA	4.15	1.93
10%MA+10%RA+80%CSA	4.15	1.91
15%MA+15%RA+70%CSA	4.24	1.88
20%MA+20%RA+60%CSA	4.75	1.81
25%MA+25%RA+50%CSA	4.75	1.77
30%MA+30%RA+40%CSA	4.24	1.84

3.8. California Bearing Ratio Test

Table 9 presents the results of the CBR test for blended CSA with marble chips and red ash at different proportions, aiming to meet the required ERA standard specification for crushed stone aggregate for use as Base Course Material (GB1). This result shows that CBR values of the blend decreases with increment of MA and RA, falling below the specification for increments beyond 20%. It is evident that all blends containing less than 20% of RA and MA satisfy the ERA standard specification, which recommends CBR values greater than 100% for base coarse material of (GB1 and GB2). Moreover, the swelling values, ranging between 0.01 and 0.04, suggest that the soaking of aggregate material has minimal effect on the swelling property values. Therefore, the marble chips and red ash aggregate can be used up to 20% for base course (GB1 and GB2) materials as a pavement construction without significant concerns regarding strength issues.

Table 9 California Bearing Ratio Values for Samples

Percentage of CSA in the blend (With RA& MC)	**Red ash (RA)**	**CSA**	**Marble chips (MA)**	**5%RA+5%MA+90%CSA**	**10%RA+10%MA+80%CSA**	**15%RA+15%MA+70%CSA**	**20%RA+20%MA+60%CSA**	**25%RA+25%MA+50%CSA**	**30%RA+30%MA+40%CSA**	**ERA, AASHTO, BS, ASTM Specification**
CBR (%)	55.4	116.3	83.6	113.90	110.70	106.50	102.5	98.90	92.80	>100%
Swell (%)	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.01	0.01	<=2

4.0 CONCLUSIONS

Based on the findings of this study, the following conclusions can be drawn:

- The engineering properties of tested samples show that neat red ash has relatively less flakiness and elongation index than crushed stone aggregate, marble chips and their blend. However, when blending these materials, it was observed that the FI decreased from 19.42% to 18.61% and the EI decreased from 22.6% to 20.77% with the increment of MA and RA from 5% to 20%.

- The two mechanical properties of samples, ACV and AIV, were tested and it was determined that all samples exhibited robust resistance to abrasion, crushing, and sudden loads, with their values falling within the standard specification requirements. However, the test results revealed an increase in the Aggregate Crushing Value (ACV) from 12.77% to 25.92% and Aggregate Impact Value (AIV) from 8.5% to 16.8% with the addition of 5% to 30% of MA and RA. This rise can be attributed to the relatively lower toughness of marble chips and red ash blended into the samples.

- Based on the Los Angeles Abrasion Test, the hardness property of blended CSA with RA and MA shows improvement as the percentage of red ash and marble chips increased. From the results, it was observed that the Los Angeles Abrasion Value (LAAV) increased from 7.32% to 14.52% with the increased percentage of MA and RA from 5% to 30%. Additionally, the specific gravity and water absorption values for the samples remained within the ERA specification of 2.65% and 2%, respectively, for replaced values of 20% of MA and RA. Importantly, the CBR values of the samples indicate that up to a 40% replacement of crushed stone aggregate with 20% red ash and 20% marble chips allows for the maintenance of standard specifications.

- The optimal blend of Red ash and Marble chips with CSA material which meets all ERA technical specifications for base course construction, comprises 20% red ash and 20% marble chips by mass when mixed with 60% crushed stone aggregate. This composition ensures that the percentage of red ash and marble chips can maintain the required quality within standard specifications.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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