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THE COMPARATIVE EXPERIMENTAL STUDIES ON THE SUITABILITY OF CERAMIC WASTE AGGREGATE AND RECYCLED ASPHALT PAVEMENT AGGREGATE AS AN ALTERNATIVE FOR BASE COURSE MATERIAL

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Abstract — The study aimed to assess the suitability of ceramic waste aggregate and recycled asphalt pavement aggregate as an alternative for base course material. An experimental research design method and Non-Probability sampling techniques were used. The comparative analysis of ceramic waste aggregate and recycled asphalt pavement aggregate were blended with crushed stone aggregate at different proportions by weight and their laboratory result was compared with standard specifications. The study results showed that the aggregate crushing value (ACV) for neat crushed stone aggregate (CSA) and recycle asphalt pavement (RAP) were 19.20% and 8.20% respectively and the blended CSA with 10%, 20%, 30%, 40% and 50% of RAP were 18.20%, 16.4%, 15.90%, 14.40%, and 13.10% respectively. Similarly, 24.32% - 12.06% for Los Angeles abrasion (LAA) and 18.50% - 12.60% for aggregate impact value (AIV) were found. The CBR test for different proportions of RAP (10% - 50%) blended with CSA was also conducted and an economically acceptable result of 104.20% was found at 30% RAP mix at 98% maximum dry density (MDD). Additionally, the California Bearing Ratio (CBR) test result for 100% RAP at 98% MDD was 49.10%. On the other hand, the experimental tests were conducted on different proportions of ceramic waste aggregate (CWA) (10%, 20%, 30%, 40%, and 50%) which satisfy the principal mechanical properties of aggregate materials. The ACV result for neat CWA was 26.70% while the blended CWA-CSA aggregate was tested with 10%, 20%, 30%, 40%, and 50% of CWA with its complement of CSA as indicated and at 20% CWA replacement of CSA test results were 21.60%, for ACV, 26.31% for LAA, 106.9 for CBR and 20.60 for AIV. For this investigation, economically acceptable results were achieved by satisfying the Ethiopian road authority (ERA) standard specification limit at 20% CWA and 30% RAP blended with CSA for base course construction material.

Keywords: Base course, ceramic waste aggregate, recycled asphalt pavement, standard specification, percentage by weight

1.0 INTRODUCTION

Road transport is one of the major modes of transportation in the world specifically in developing countries for transporting human beings and raw materials from one place to other at the required time and place. The economic and social interaction between two or more countries can be accelerated by exchanging their needs by importing and exporting industrial and agricultural products. One of the strategic visions of the Ethiopian government by 2028 is to transform the country into generating a middle income and also by sustaining the two-digit economic growth recorded in recent years (2003–2010/11). Therefore, this vision mainly depends on expanding the infrastructure constructed in the country, constructing new durable road pavement and improving existing road network [1]. The construction industry is one of the pillars of the economic driving sector that supports the financial system in Ethiopia. It contributes 5.3% of GDP and public works projects account for an average annual share of 58.2% of the government's capital budget. Since 1997, the Ethiopian Roads Authority has begun to coordinate road improvement work entitled the "Road Sector Development Program" (RSDP) in three phases from 1997 to 2010 with an estimated budget of US$1.2 up to US$2.2 billion [2]. Mineral aggregates are hard, inert materials that are mixed with the cementing medium asphalt to form pavements. Aggregates are the main components of an asphalt concrete pavement and the total 90- 95% of the mixture by weight. Recycling of pavement materials is used in the road construction industries. Resource conservation, Environmental preservation, and retention of existing geometrics are merits obtained due to recycling of road-making materials. Ceramic products for major building construction material as wall tiles, floor tiles, sanitary ware, household ceramics, and technical ceramics [3]. Depending on the sources of raw materials ceramic wastes are classified into two: Generated fired ceramic wastes and fired ceramic wastes. Generated fired ceramic wastes use red pastes for product (brick, blocks, and roof tiles) manufacture while fired ceramic wastes are made from stoneware ceramic [4]. In the process of manufacturing ceramic 30% of the material goes to waste and there is a need for exploring innovative ways to re-use it [5, 6]. Due to the increasing demand for aggregate in the construction industry researcher worldwide searched for alternative materials and identified ceramics to replace natural aggregates [7, 8]. Some investigations revealed that ceramic wastes are good to substitute conventional aggregates in concrete [9]. Utilization of ceramic waste can solve problems of aggregate shortages and minimize environmental and disposal issues. Re-using asphalt pavement become a common practice due to its environmental, economic, and social benefits. The reason behind the recycling of RAP includes the reduction of construction waste materials, preservation of non-renewable natural resources, and lower energy costs. Cost savings and environmental benefits of using recycled materials are optimized with the performance of pavement performance during its design life. Aggregate material characteristics like; mineralogy, particle size distribution (grading) and fines content, particle shape, surface texture, and angularity as well as its durability (soundness, abrasion resistance) affect the performance of the road by affecting the workability of the mixture and controlling the degree of compaction (density) and pore structure of the layer in addition to layer strength, stability (resistance to deformations), and modulus (stiffness) properties that are relevant to performance and design [10]. The elimination of disposal problems, conservation of natural aggregate, cost, and energy savings, including those related to avoiding the processing of virgin material are some benefits of using RAP [11]. The cheapest construction materials with good performance of pavement structure are a burning issue for developing countries like Ethiopia. Hence it continuously increase the cost of new conventional construction materials, so the researcher can explore alternatives and cheaper the overall cost of construction without compromising quality during design and construction. Road infrastructure is the gear that accelerating the economic growth of the society [12].

Currently the government of Ethiopia gives more emphasis on the road network construction throughout the country by using the flexible types of pavement and there was a continuous maintenance of existing to keep the road network efficient and safe to accommodate daily increased traffic volumes [13]. There are various materials required for constructing a new pavement and maintaining the existing pavements materials such as aggregate, bitumen, and fillers. The performance of pavement is the fluctuations of quality construction materials [14]. Despite the increasing the price of bitumen and aggregate over time and the scarcity of new aggregate, building materials and maintaining road network structures is also a challenge. In order to reduce such a problem, reusing existing materials with an understanding of the impact on mixture properties through modification and utilization are the best alternatives for road material construction. In Ethiopia, due to rehabilitation and maintenance, a large amount of RAP is produced per year. But the use of recycled materials for an asphalt concrete pavement is not a common, and also a vast quantities of the RAP aggregates remain unutilized. Other difficulty encountered during applying a RAP aggregate in hot mix asphalt is the cause of the effect of using RAP aggregate a proportion on asphalt mix performance, which leads to a cracking, low durability, and has low strength of the flexible pavement. Since the physical properties of RAP aggregate are not the same as that of the new aggregates in the concrete mix, it caused aging, loading problem, and low quality of aggregates. Those problems attracted the researcher's consideration to search for materials as a construction and maintenance of flexible pavement by using the existing RAP aggregates as partial replacement of virgin crushed aggregate by considering the effects of RAP aggregate on asphalt concrete mix properties and recommends the optimum proportion of the RAP aggregate used in hot mix asphalt. On the other hand, the previous research result shows from the annual production of the ceramic industry it is expected that about 30% is converted to waste [15]. And every year hundreds of thousands of tons of ceramic waste were generated worldwide [16]. Using ceramic waste in HMA as a base course material was an effective way to prevent environmental pollution. Previous study results showed that the addition of ceramic waste aggregates provides better performance properties to HMA. Additionally, it was observed that up to 30% of natural aggregates can be replaced by the ceramic waste in HMA [17]. Natural resources required for various constructions are getting depleted at a rapid rate. This led the researchers in finding other substitutes for the production of construction materials by keeping in mind of maintaining the quality, strength and durability. Currently, there is a growing interest in using waste materials such as ceramic waste aggregate and recycled asphalt pavement aggregate as alternative base course materials for asphalt construction. However, this is a relatively new concept and poorly practiced especially in our country Ethiopia. Replacing the crushed aggregates with high-quality, cost-effective and environment-friendly recycled aggregate materials such as ceramic waste aggregate and recycled asphalt pavement aggregate is crucial for developing countries like Ethiopia. Therefore, this study was undertaken to analyze and compare the suitability of ceramic waste aggregate and recycled asphalt pavement aggregate as an alternative material for base course and to evaluate its practicability in road construction.

2.0 MATERIALS AND METHODS

2.1 Material Required

Non-probable purposive sampling techniques were adopted to collect materials used for conducting this research method.

- Ceramic waste aggregate (CWA), recycled asphalt pavement aggregate (RAPA), and crushed stone aggregate.

2.2 Study Design

An experimental comparative study design was employed in the current study as illustrated in Figure 1.

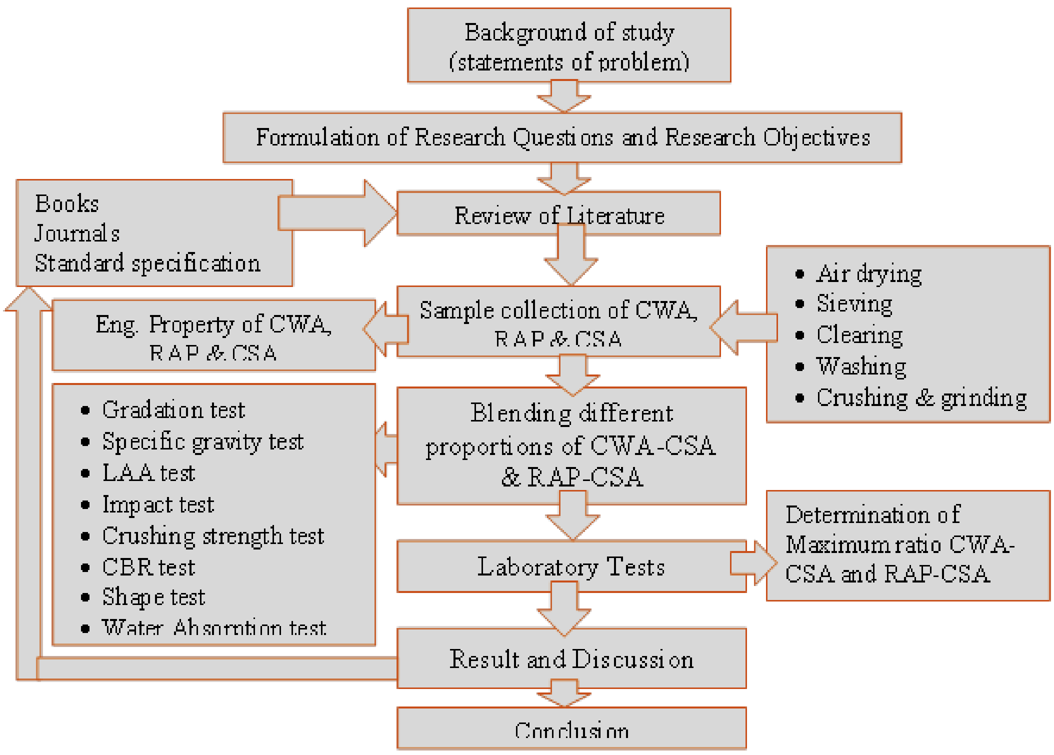

Figure 1 Flow chart showing study design

2.3 Sample Preparation Procedures

Representative samples were collected as recommended in AASHTO T-2 and a mechanical splitter was used in order to collect a representative sample for all tests as shown in Figure 2. The details of this procedure can be referred to in AASHTO T – 248.

Figure 2 Photo of sampling, extraction of RAP, and preparation of samples for laboratory tests

2.3.1 Mix design

The laboratory test was conducted according to the following mix design: the Non-Probability sampling techniques were adopted to collect samples and to prepare the mix by mechanical blending by weight proportion. i.e.,

i. CSA-RAP mix by: 90%CSA + 10% RAP, 80%CSA + 20% RAP, 70%CSA + 30% RAP, 60%CSA + 40% RAP, 50%CSA + 50% RAP.

ii. CSA-CWA mix by: 90%CSA + 10% CWA, 80%CSA + 20% CWA, 70%CSA + 30% CWA, 60%CSA + 40% CWA, 50%CSA + 50% CWA.

2.4 Standards and Specification for this Study

Table 1 Standards and specification for this study

Test Type	Test Method
Extraction by Centrifuge Method	ASTMD 2172
Los Angles Abrasion value	AASHTO T-96
Aggregate crushing value	BS 812, Part 110
Aggregate Impact Value	BS 812, Part 112
Elongation index	BS 812, Part 105
Flakiness index	BS 812, Part 105
Specific Gravity of Coarse Aggregate	AASHTO T 85
Specific Gravity of Fine Aggregate	AASHTO T 84
Water absorption	BS 812, Part 2
A sieve analysis	AASHTO T-27
Blending	ASTMD 3515

3.0 RESULT AND DISCUSSIONS

3.1 Aggregate (CSA, CWA & RAPA) Gradation

Gradation (Particle size distribution) of a particular pavement aggregate has to be checked continuously to maintain the required particle size and quantities. Accordingly, the analysis of particle size distribution was used to determine the proportion of gravel, sand and fine of CSA, RAPA and CWA samples and the results were presented in Figure 3 as followed.

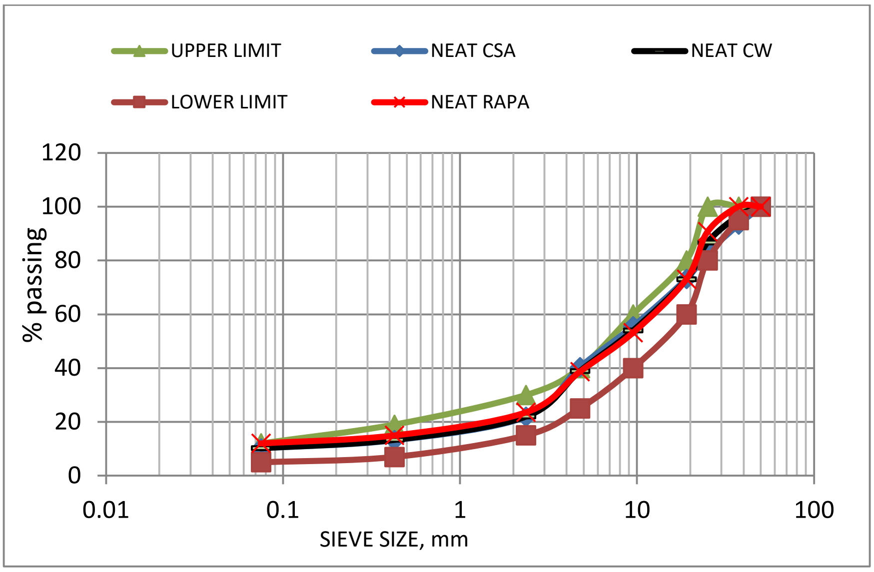

Figure 3 Aggregate gradation curve for CSA, RAPA and CWA

Based on the Ethiopian road authority manual 2013, pavement design manual conventional aggregate was classified as graded crushed stone (GB1) and the grading limit of this material for 37.5mm nominal maximum aggregate size was used. As it was observed from the result Figure 3 above, RAPA contains a higher courser than that of a crushed natural aggregate compared to GB1 base course material standard depending on the milling and stockpiling operation. The result recorded above also above shows the ceramic waste aggregates fall within the limit. Generally, the Table 2 and Figure 3 reveal that the gradation results of CSA, RAPA and CWA were between upper and lower limits and recommended to use as GB1 according to ERA specification. So, the gradation was accepted and suitable for the pavement construction materials.

3.2. Classification of Soil

Based on AASHTO soil classification CSA, CWA and RAPA under investigation are classified as granular materials because of percentage passed sieve #200 is less than 35%. Further classification is required as granular material grouped in to A-1, A-3 and A-2 sub-groups. This is done by having the sieve value of each sample passing number #10, #40 and #200 sieve sizes in addition to PI value. Hence all materials are grouped under A-1-a type of soils due to having less than 15% of particles passing 0.075mm, less than 30% passing the sieve no. 40 and less than 50% pass the No. 10 sieve with PI < 6. In the AASHTO classification system and A-1-a soil is preferred for highway construction soil.

Table 2 AASHTO soil classification for neat CSA, RAPA and CWA

Sample reference	% passing sieve number			Atterberg's limits			Classification
	#10	#40	#200	LL	PL	PI	
CSA	21.90	13.19	10.19				A-1-a
CWA	22.03	13.35	10.23		NP		A-1-a
RAPA	23.77	15.30	12.13				A-1-a

NP-Non-plastic

3.3 Aggregate Gradation Evaluation for CSA-RAPA and CSA-CWA Mixes

The CSA-RAPA and CSA-CWA were compared with the ERA standard specification designated for a base course to evaluate their engineering properties. 10%, 20%, 40% and 50% of RAPA and 10%, 30%, 40% and 50% of CWA respectively were out of limit GB1 requirement of gradation when compared with ERA standard specifications. Therefore, it requires augmentation with fresh aggregate to meet the standard specification. Through trial and error, 30% RAPA and 20%CWA blended with 70% and 60% of fresh aggregate respectively were fitted with ERA specification for GB1 base course. Figure 4 and Figure 5 shows aggregate gradation for CSA-RAPA and CSA-CWA mix based on the ERA standard specification. The gradation upper limit and lower limit are indicated with a different color.

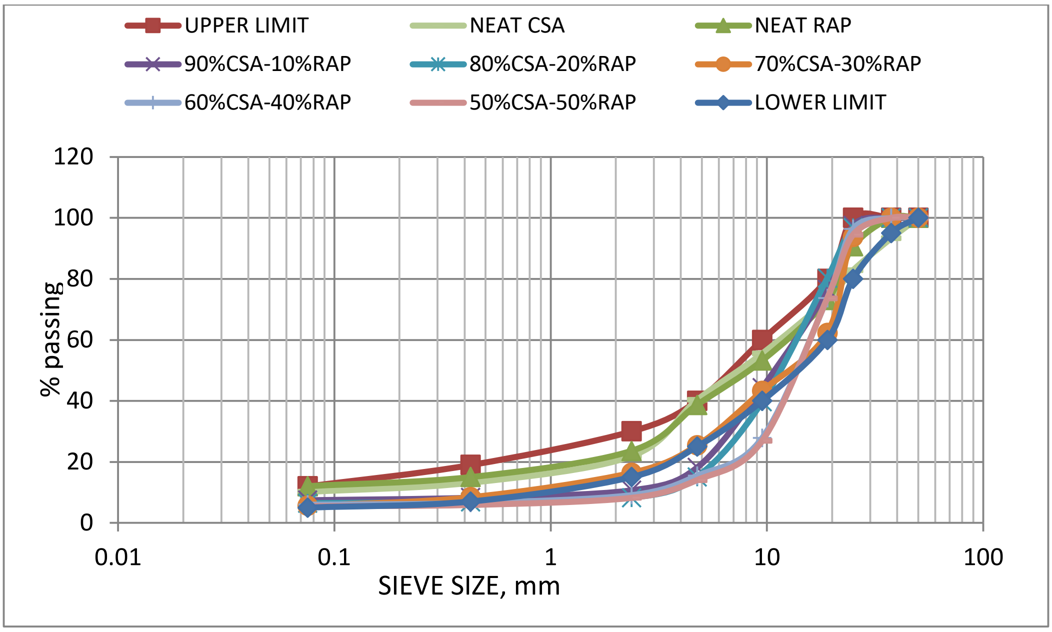

Figure 4 Gradation result of blended CSA-RAPA

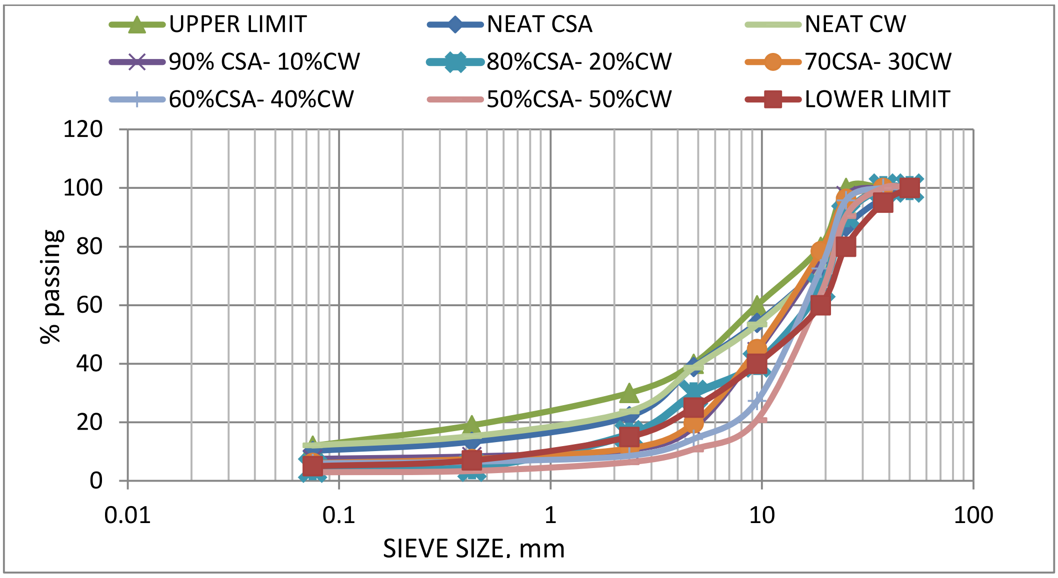

Figure 5 Gradation result of blended CSA-CWA

3.4 Effect of CWA on ACV, AIV, LAA, Flakiness Index, and Water Absorption Value of CSA

Water absorption and bulk density were decreased with increasing percentage of replacement while ACV, AIV, LAA and FI were increased with increasing percentage of replacement as indicated in the Table 3 and Figure 6 and Figure 7. The laboratory test result revealed that ACV for pure CSA and CWA was 19.2% and 26.7% respectively.

ACV test was conducted on mixture of CSA and CWA with 10%CWA-50%CWA and the results were more promising. Additionally, AIV tests were conducted on different proportions of CSA and CWA mixtures from 10%CWA-50%CWA at 10% increment and all results satisfy the standard specification for base course material. By considering the cost of construction 20% of CWA with 80% CSA was selected as the optimum replacement with 20.60 AIV value which is within the limit of ERA standard specification (<30%).

Table 3 Physical properties of crushed aggregate and CSA-CWA mixes

Tests	Results							ERA Specification requirements
	0% CWA	10% CWA	20% CWA	30% CWA	40% CWA	50% CWA	100% CWA	
Bulk dry S.G	2.72	2.71	2.66	2.63	2.63	2.62	2.58	
Bulk SSD S.G	2.77	2.75	2.70	2.67	2.66	2.65	2.60	> 2.65
Apparent S.G	2.85	2.83	2.78	2.73	2.72	2.71	2.65	
Water absorption, %	1.60	1.56	1.51	1.38	1.26	1.19	1.09	<2
Flakiness Index	18.41						19.89	<30
Los Angeles Abrasion (LAA),%	25.5	25.77	26.31	26.97	27.34	28.11	32.31	<51
Aggregate Crushing Value (ACV), %	19.2	20.2	21.6	22.5	23.8	24.7	26.7	<29
Aggregate Impact Value (AIV), %	18.5	19.2	20.6	21.0	21.9	22.5	25.2	<30

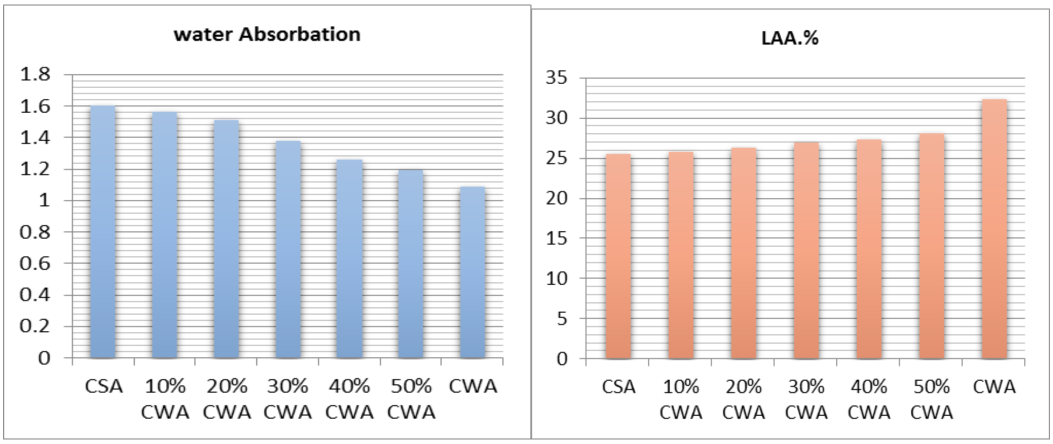

Figure 6 Effect of CWA on WA and LAA

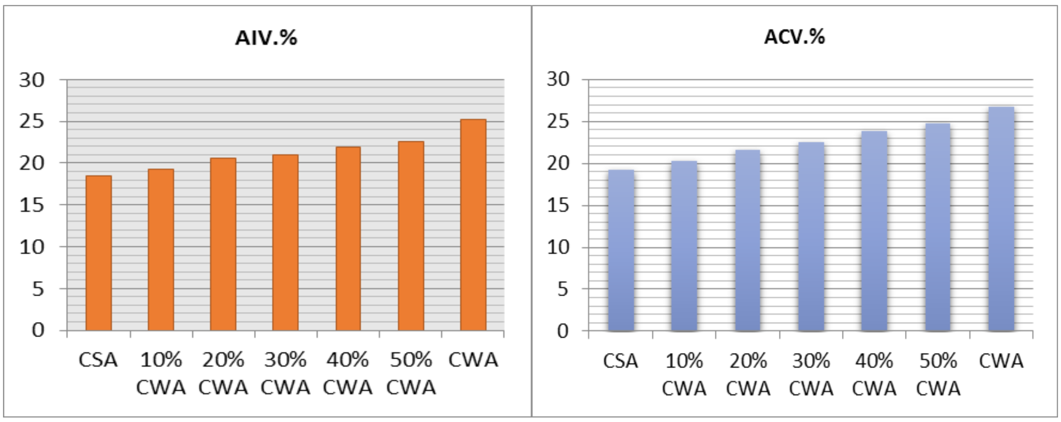

Figure 7 Effect of CWA on WA and ACV

As indicated in the Figure 6 above the laboratory test result of LAA for neat CSA and CWA was 25.5% and 32.31% respectively. These values were within the ERA standard specification for base course material which is < 51%. According the summary of test result in Table 3 flakiness and elongation index obtained from laboratory tests for CWA was 19.86 %, this indicates the CWA was suitable for use as a base coarse materials and within the ERA standard specification limit. Specific gravity test was also conducted on CWA mixed with CSA by varies percentage and acceptable result was found at 20% CWA mix with 80% CSA which was 2.78 and falls within ERA specification for specific gravity > 2.65. The water absorption test result for net CWA was 1.09% and 1.51% for 20%CWA mixed with 80% CSA; this was also within ERA specification for specific gravity < 2.

3.5 Effect of CWA on MDD and OMC Values of CSA

As it was clearly observed from Figure 8 below, the optimum moisture content decreased from 9.65% to 6.78% with increasing percentage of ceramic waste aggregate (from 10% to 50% CWA) due to smoothness and water resistance capacity of ceramic waste. Whereas, maximum dry density was decreased as a percentage of ceramic waste aggregate increased slightly from 2.05 gm/cm^3 to 1.84 gm/cm^3 at 10% CWA and 50%CWA replacement of CSA respectively.

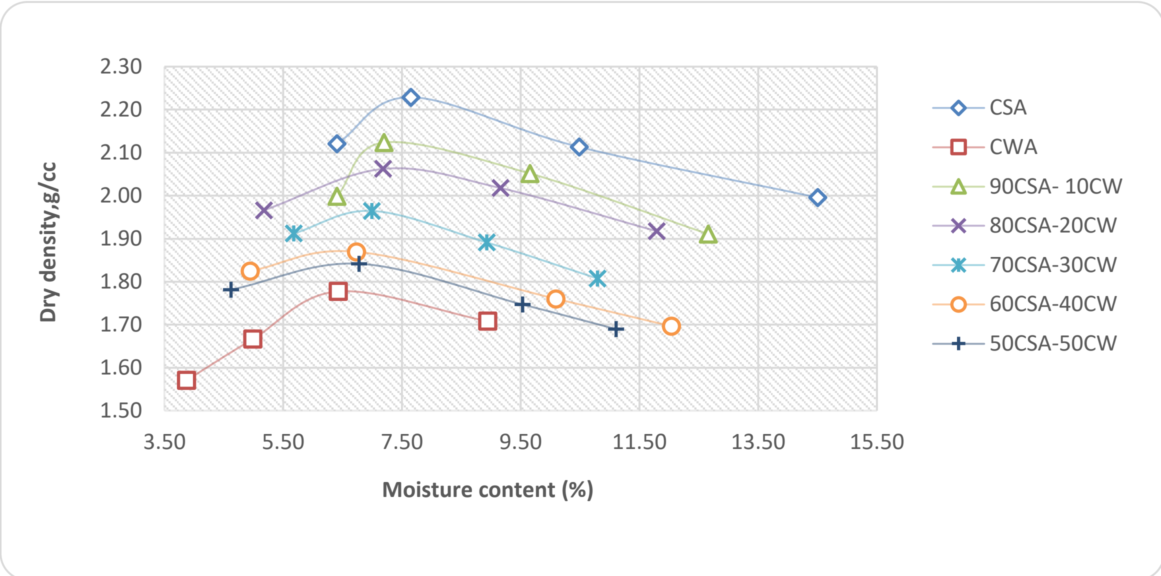

Figure 8 Graph of moisture-density relation of blended CSA-CWA sample

3.6 Effect of CWA on CBR Values of CSA

The CBR test result for 100%CWA at 98%MDD was 43.20% which was less than the ERA standard specification for GB1 base course materials. On the other hand, CBR test was also conducted for different proportion of CWA mix with CSA (10%CWA -50%CWA) as shown in Figure 9. Based on this, an acceptable result was found at 20% CWA mix which was 106.90% at 98%MDD. This result satisfies the ERA standard specification for base coarse materials >100% satisfies the minimum requirement.

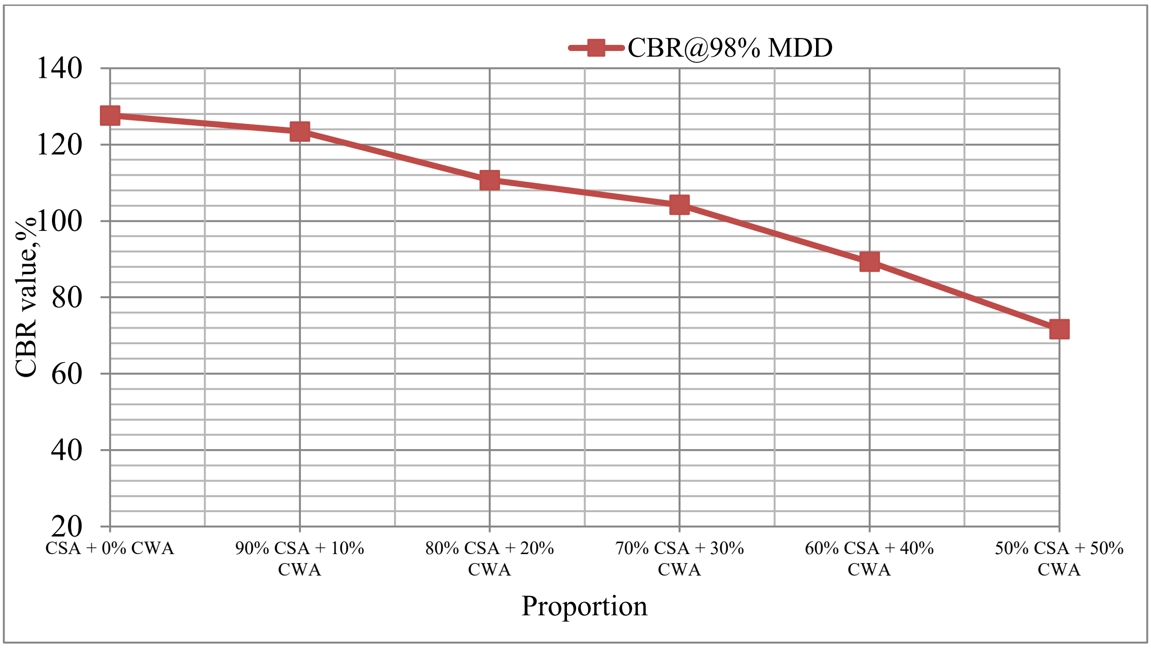

Figure 9 CBR test results for Blended CSA-CWA Sample

3.7 Effect of RAPA on ACV, AIV, LAA, Flakiness Index, and Water Absorption Value of CSA

The laboratory tests were conducted on physical properties of CSA and varies percentage replacement of RAPA (10%, 20%, 30%, 40%, and 50%) for base course material as shown in Table 4 below. The ACV result shows that replacing CSA with different percentage of RAPA were within ERA standard specification requirement for GB1 base course material which requires a maximum value of 29%. The ACV value for neat RAPA was 8.2% and found within the ERA standard specification limit. Similarly, it was observed from Table 4 that AIV test results of both materials have a big difference, 18.5 and 9.4 respectively. The lower the aggregate impact value the greater resistance capacity to impact (toughness) sudden load. The AIV tests were also conducted on the combination of CSA at different percentages of RAPA (10%, 20%, 30%, 40%, and 50%) and as per ERA specification, the blended results of both materials proved good resistance under sudden traffic force. Table 4 also shows that flakiness and elongation index obtained from laboratory tests for RAPA was 12.65%, indicating that the RAPA sample was suitable for use as a base coarse material because it is within the ERA standard specification limit that is FI <30%. Moreover, RAPA also satisfies both requirements of the shape test. Flakiness index conducted for fresh stone aggregate used for this study as base course material having flakiness index result of 18.41% which was much less than the maximum limit of ERA specification.

Table 4 Physical properties of CSA and RAPA for the study

Tests	Results							ERA Specification requirements
	0% RAPA	10% RAPA	20% RAPA	30% RAPA	40% RAPA	50% RAPA	100% RAPA	
Bulk dry S.G	2.72	2.70	2.67	2.66	2.65	2.63	2.61	
Bulk SSD S.G	2.77	2.73	2.71	2.70	2.68	2.67	2.63	> 2.65
Apparent S.G	2.85	2.80	2.78	2.76	2.74	2.72	2.68	
Water absorption, %	1.60	1.44	1.40	1.35	1.27	1.24	0.99	<2
Flakiness Index	18.41						12.65	<30
Los Angeles Abrasion (LAA),%	25.5	24.32	22.08	16.28	15.43	12.06	8.22	<51
Aggregate Crushing Value (ACV), %	19.2	18.2	16.4	15.9	14.4	13.1	8.2	<29
Aggregate Impact Value (AIV), %	18.5	15.9	14.8	13.2	12.6	12.0	9.4	<30

In the Table 4 above, the laboratory test result of LAA for neat RAPA was conducted and found a value of 8.22%. This indicates that the hardiness of RAP with promising crushing value under heavy traffic. Accordingly, the appropriate LAA result 16.28% was found at 30% RAPA replacement and selected as best fit to use as base course material for construction of flexible pavement. The pure CSA water absorption result was 1.60% while that of neat RAPA is 0.99%. The water absorption of 30% RAPA with 70% CSA was 1.35% and it was also fit within ERA specification for specific gravity > 2.65. As a percent of RAPA blending were increased both specific gravity and water absorption were decreased.

3.8 Effect of RAPA on MDD and OMC Values of CSA

As it was clearly observed from Figure 10 the OMC of the mixtures decreased from 7.36% to 6.87% with increasing percentages of RAPA from 10% to 50%. From the result, we observe that the increase in RAPA content decreases MDD and OMC values this is due to the coat on asphalt concrete prevent compaction by consolidation and minimizing the number of fines in RAPA particles.

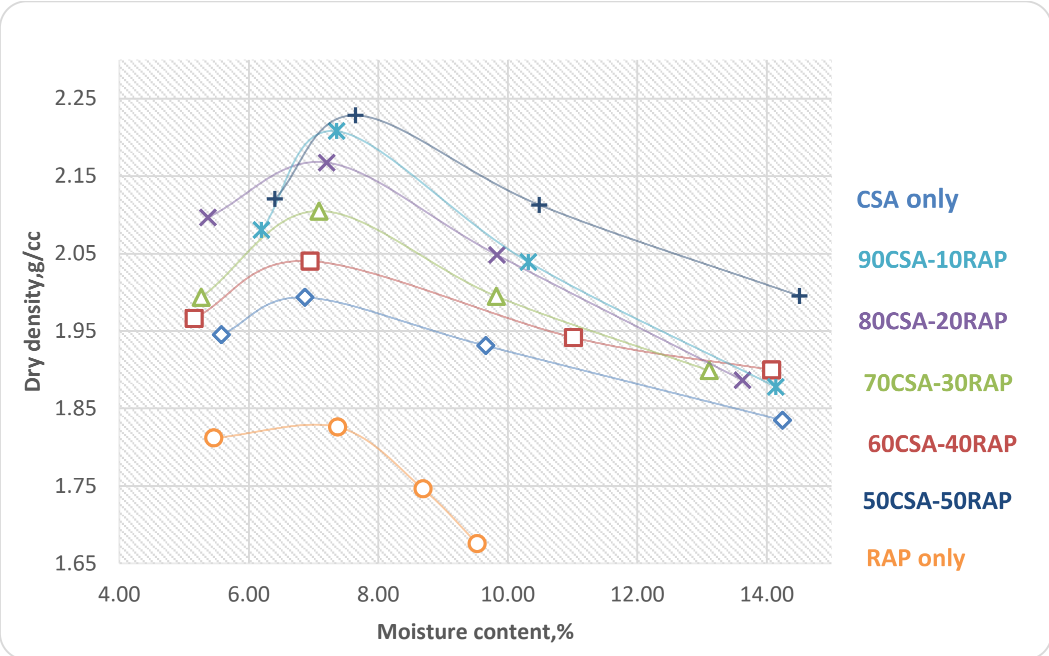

Figure 10 Graph of moisture-density relation of blended CSA-RAPA

3.9 Effect of RAPA on CBR Values of CSA

The CBR value of the soil was found to be decreased from 127.6 to 71.7% as the content of RAPA increased from 0% to 50% as shown in Figure 11. The CBR values of 10%, 20% and 30% fulfill the requirement of GB1 ERA specification. Accordingly, the acceptable result satisfies the ERA standard specification for base coarse materials was found at 30% RAPA and 70% CSA mixture which was 104.20% at 98% MDD. Hence 30% addition of RAPA was selected as the optimum replacement to be added in order to build an economical road base.

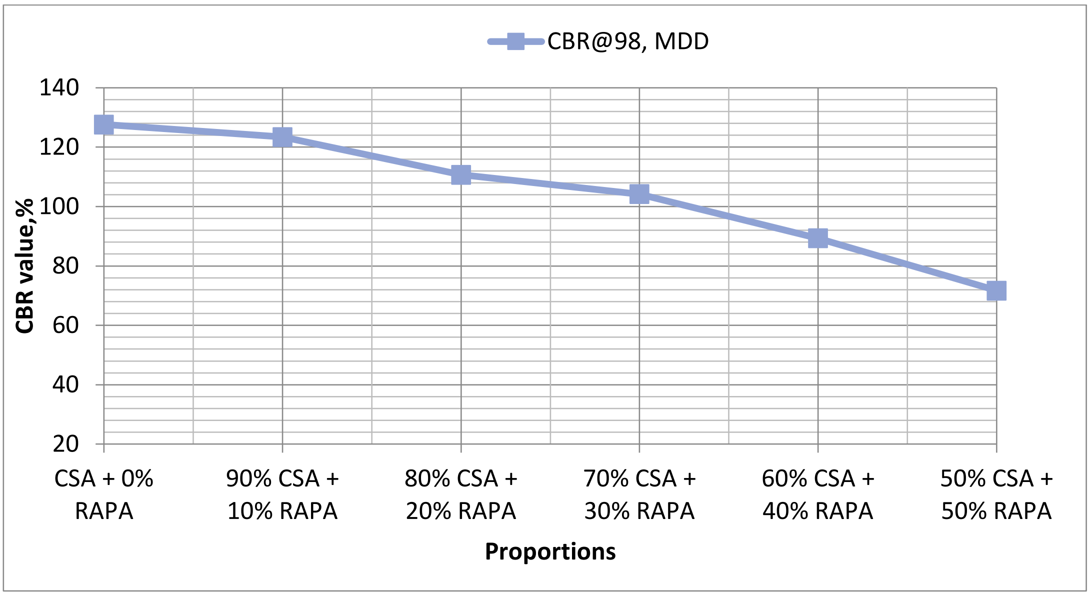

Figure 11 California Bearing Ratio (CBR) test result for CSA-RAPA Sample

4.0 CONCLUSIONS

From the test results as well as the analysis and discussion the following conclusions were drawn:

- The Sieve analysis results show that gradation of neat CSA, RAP, CWA as well as blended RAP-CSA and CWA-CSA at different percentage of mix are parallel to a standard specification of ERA. The material contains gravel and sand and is classified as A-1-a.
- The study has shown that the ACV result for neat CSA and RAP are 19.20% and 8.20% respectively. The RAP- CSA blends aggregate tested in replacement of unbound base course GB1 with 10%, 20%, 30%, 40% and 50%of RAP with its complement of CSA as indicated were 18.20%, 16.4%, 15.90%, 14.40%, and 13.10% respectively. Similarly, a 24.32% - 12.06% for LAA and 18.50% - 12.60% for AIV was found as the maximum and minimum value of the test.
- The current study test result for moisture content and dry density of the different percentage of RAP mixture with CSA were 7.36% for 10%RAP-90%CSA, 7.20% for 20%RAP-80%CSA, 7.08% for 30%RAP-70CSA, 6.95% for 40RAP-60CSA, and 6.87% for 50%RAP-50%CSA. The optimum moisture content of the mixtures decreases with increasing percentages of RAP aggregate in the mixtures. A specific gravity test result showed that RAP sample has a specific gravity value of 2.68 and 2.85 for that of neat CSA. Specific gravity test result for RAP mix with CSA by percent and the economically acceptable result was found at 30% RAP mix with CSA which is 2.76 that fall within ERA specification for specific gravity greater than 2.65.
- Its CBR test was also conducted for a different proportion of RAPA mix with CSA (10%RAP -50%RAP). Thus, an economically acceptable result is found at 30% RAPA replacement was 104.20% at 98%MDD. This result satisfies the ERA standard specification for base coarse materials and is selected as the optimum percentage of replacement. The ACV result for neat CWA is 26.70%. The CWA- CSA blends aggregate was tested in replacement of unbound base course GB1 with 10%, 20%, 30%, 40% and 50% of CWA with its complement of CSA as indicated and at 20%CWA replacement with CSA were (21.60%, for ACV), (26.31% for LLA), (106.9 for CBR) and (20.60 for AIV).

Conflict of Interest

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

Acknowledgement

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