Asia-Pacific Journal of Science and Technology: Volume: 30. Issue: 02. Article ID.: APST-30-02-02. Research Article

APST

Asia-Pacific Journal of Science and Technology

https://www.tci-thaijo.org/index.php/APST/index

Published by Research Department,
Khon Kaen University, Thailand

Strength properties of crushed Mangima Stone as coarse aggregate for pavement base materials stabilized with sugarcane bagasse ash

Vera Karla S. Caingles* and Edgem Lloyd S. Balabis

Faculty of Civil Engineering, University of Science and Technology of Southern Philippines, Cagayan de Oro City, Philippines
*Corresponding author: vera.karla@ustp.edu.ph

Received 30 January 2024
Revised 1 May 2024
Accepted 31 May 2024

Abstract

The demand for base coarse materials has increased as a result of the fast growth in road infrastructure development, imposing stress on the available resources. To address this problem, this study explores the viability of using Portland cement, sugarcane bagasse ash, and Mangima aggregate as the fundamental components for road bases. An extensive number of laboratory experiments, including the Sieve Analysis Test, Liquid Limit and Plastic Limit Test, Abrasion Test, Modified Proctor Test, California Bearing Ratio (CBR), and Unconfined Compression Strength (UCS). Stabilized base coarse composed of two sets, control mix: (Mangima stone + soil + cement) and design mix (Mangima stone + soil + cement + varying amount of sugarcane bagasse ash (SCBA) of 1%, 2%, 3%, and 4%). Results revealed that the mixture of 3% sugarcane bagasse ash and 6% cement yielded the highest Maximum Dry Density (MDD), CBR, and UCS values of 2101 kg/m^3, 102.6%, and 102.6psi, respectively Hence, the results of this study indicate that 100% Crushed Mangima aggregate replacement, combined with 6% cement and 3% SCBA can indeed be considered as a viable alternative coarse aggregate for road base applications. Moreover, further study on increasing the amount of SCBA while decreasing the amount of cement is recommended.

Keywords: Base coarse materials, Mangima stone, Materials engineering, Sugarcane bagasse ash

1. Introduction

In most developing countries, road transport is rapidly becoming one of the main factors in fostering economic development [1, 2]. Basically, in the transportation sector, road infrastructure is the medium of transportation that plays a vital role in the delivery and distribution of goods and services from one place to another. The availability and accessibility of these roads are significantly useful in performing the daily activities of the community and the needs of the economy. Hence, proper planning and implementation of the road infrastructure provide a crucial contribution to the development and growth of the country’s economy as well as social benefits.

Rigid or flexible pavement is one of the road infrastructures. The base course is part of the pavement structure layered below the surface coarse. This is composed of unbound materials like gravel or crushed stone or materials stabilized/treated with asphalt, cement or lime [3]. It directly receives the vehicle load from the upper layer of the pavement. Various literatures displayed studies on alternative innovation for base coarse materials by improving its properties through incorporating other granular materials or stabilization. These include studies on the base coarse blended or mixed with marble waste [4], the replacement of aggregate base coarse with limestone [5] and blended with waste limestone [6], and using of recycled aggregates from building and road construction and demolition [7]. Also, there were studies on stabilizing the base coarse with cement [8, 9], cement slurry [10], Portland Cement and styrene-butadiene copolymer latex [11], and Portland Cement [12]. Though, it is noted that cement is the most common stabilizing agent for soil [13] and aggregates [14]. However, the global cement industry contributes to about 5–7% of the world’s CO_2 emissions [15]. With this, some articles focused on utilizing industrial wastes to stabilize such materials. A huge volume of industrial waste is generated around the world and has a negative impact on the environment due to its safe disposal. These industrial by-products include slags and ashes such as copper, steel, blast furnace, bagasse, lime sludge, etc. [16]. Hence, studies on the potential application of these wastes bring significant solutions relevant to environmental issues and concerns related to waste disposal and management.

Bagasse ash is a sugarcane fibrous residue after the extraction of its juice. It is considered one of the world's largest agricultural residues [17]. According to [18], disposing of this waste by just dumping it in the open land causes serious threats to the community, such as air and water pollution. Meanwhile, bagasse ash is identified as pozzolanic material [19] because it contains a high amount of amorphous silica, which enhances pozzolanic activity [20]. This gained interest among researchers to perform studies related to this waste as part of construction materials through cement replacement or as a stabilizing agent. [16] conducted a study on bagasse ash in combination with granulated blast furnace slag as a lightweight material for road construction. [21] investigated the use of bagasse ash in paver block production for low-volume traffic road pavement. Another study by [22] used bagasse ash as a filler to improve the performance of asphalt concrete pavement.

In the Philippines, the Department of Public Works and Highways (DPWH) provides effective standard specifications for the implementation of all government projects to produce sound, robust, and cost-effective structures. The specifications and guidelines for road mix base coarse stabilized with Portland cement are under ITEM 204 of the DWPH Standard Specifications for Highways, Bridges, and Airports book. The Bureau of Research and Standards (BRS) of this department conducted a stabilization study of laterite soil for road base/subbase material [23]. The study was performed to utilize indigenous materials as base/subbase material. The stabilizers used were lime, cement, and gypsum. Meanwhile, Mangima stone is abundant in the province of Bukidnon. This has been harvested in the cliff walls, cut into a manageable size, and sold as building decorative. It had been studied as concrete aggregates, and it was proven that it could produce a good result [24-26]. Moreover, Bukidnon accounts for 72% and 75% overall sugarcane plantation area and sugar production of Mindanao, respectively [27]. Currently, there are two sugar milling companies in this province. Hence, this study aimed to investigate the potential application of Mangima stone as an aggregate coarse replacement in a base road material added with cement and sugarcane bagasse ash.

2. Materials and methods

2.1 General procedure

The methodology of this study consists of firstly, the collection of the materials such as the soil-aggregates which consist of any combination of gravel, sand, silt, and clay; Mangima stones, cement, and sugarcane bagasse ash. Second, the laboratory tests for the gathered materials. Third, the proportioning of the stabilized base coarse sample materials in which the conventional coarse aggregates of the base coarse were totally replaced with Mangima stone and stabilized constant amount of cement and varying amounts of sugarcane bagasse ash after calculating the required amount based on the percentages of materials as stabilizers. Fourth, laboratory tests were performed, including a compaction test, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) to the modified base coarse and stabilized modified base coarse samples. Lastly, the results of all tests for both the modified base coarse and stabilized modified base coarse samples were discussed and explained hence, significant findings were drawn.

2.2 Soil specimen proportioning

There were two sets of samples prepared in this study, namely, set A is the modified base coarse, and set B is the stabilized modified base coarse. For the modified base coarse, the percentage of the coarse aggregate was replaced with Mangima stone. Table 1 shows the composition of the modified sample displaying the percentage of replacement of coarse aggregate with Mangima stone. Meanwhile, the composition of the Mangima stones, conventional base coarse, cement, and sugarcane bagasse ash in a modified base coarse and stabilized modified coarse samples is presented in Table 2. The cement and SBA were used as stabilizers. For the amount of cement, a constant of 6% by weight of dry base coarse material was added as a stabilizer while a varying percentage from one (1) to four (4) percent for the sugarcane bagasse ash (SCBA).

Table 1 Composition of aggregates in modified base coarse.

Sieve Designation	Mass Percent Passing	Modified Sample Materials
2"	100	Mangima stone (Coarse Aggregate)
No. 4	45 – 100	
No. 10	37 – 80	Conventional base coarse (Fine Aggregate)
No. 40	15 – 20	
No. 200	0 – 25	

Table 2 Composition of mixtures.

Sample No.	Base Coarse (100%)		Cement (%)	SCBA (%)
	Mangima Stone (%)	Soil (%)		
Modified base coarse				
M1	55	45	0	0
Stabilized Modified base coarse				
Control Mix	55	45	6	0
Design Mix-A	55	45	6	1
Design Mix-B	55	45	6	2
Design Mix-C	55	45	6	3
Design Mix-D	55	45	6	4

2.3 Laboratory testing

All the tests were performed at the DPWH-accredited materials testing laboratory and in accordance with international standards. These include Los Angeles abrasion, sieve analysis, hygroscopic moisture content, density, liquid and plastic limits, compaction, CBR, and UCS.

3. Results and discussion

The laboratory results of the sieve analysis, as presented in Table 3, demonstrate that the modified base coarse material complies with the grading requirements outlined in item 204 of the DPWH Bluebook. It has been determined that the material falls within Grading A, indicating that it meets the specified particle size distribution criteria for the aggregate base coarse. The percentage loss based on the Los Angeles abrasion test is 27.5%, which is within the requirement of DPWH standard that the mass percent of wear should not exceed 50%.

Table 3 Test report on sieve analysis (gradation test) of the untreated conventional and control mix.

Sieve Size		Percent Passing %			
Standard (mm)	US Standard (inch)	Conventional Mixture (%)	Control Mixture (%)	Govt. Specs	
				Grading A (%)	Grading B (%)
50	2	100	100	100	100
4.75	No.4	48	45	45 – 100	55 – 100
2.00	No. 10	40	37	37 – 80	45 – 100
0.425	No. 40	20	20	15 – 20	25 – 80
0.075	No. 200	8	8	0 – 25	11 – 35

In this study, the plasticity index value for the modified base coarse mixture was determined to be 7%, as shown in Table 4. The results meet the minimum requirement for item 204, and therefore, the soil specimen has been classified as A-2-4 (0) based on the American Association of State Highway and Transportation Officials (AASHTO) classification system. This classification signifies that the soil specimen primarily consists of silty or clayey gravel sand.

Table 4 Test result of plastic and liquid limit test.

Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Control Mix	38	31	7

Furthermore, in accordance with the Unified Soil Classification System (USCS), the soil specimen has been classified as GW-GM, corresponding to well-graded gravel with silt. This dual classification provides valuable information about the soil's composition and behavior, aiding in its suitability assessment for construction purposes.

In Table 5, for the stabilized modified base coarse, the results showed that the maximum dry density (MDD) of the design mixtures was higher than the control mix with a value of 1961 kg/m^3. However, the addition of cement and SCBA to the control mix provides an increase in MDD values. The mixture that provides the highest value of MDD was the Design Mix-C (6% Cement; 3% SBA) with a value of 2101 kg/m^3.

Table 5 Maximum dry density and optimum moisture content.

Mixture	Control Mix	Design Mix-A	Design Mix-B	Design Mix-C	Design Mix-D
Maximum Dry Density (kg/m^3)	1961	2005	2026	2101	2039
Optimum Moisture Content (%)	9.2	9.3	9.2	9.0	9.0

Figure 1 shows the compaction curves illustrating the relationship between untreated and treated Cement-Dry density and Cement-Moisture content in accordance with ASTM D 1557 standards. These curves help visualize the average Optimum Moisture Content (OMC) and MDD of the proposed mixtures. It's evident from these curves that the MDD and OMC values for the design mixtures obtained from the compaction test are higher than those of the control mixture. Notably, among the design mixtures, Design Mix-C stands out with the highest MDD value compared to the others. This increase in MDD and OMC can be attributed to the treatment of the material with Portland cement. This treatment, as suggested by [28, 29], is associated with an enhancement in material quality. These findings underscore the potential benefits of using Portland cement to improve the properties of the base coarse material in construction applications.

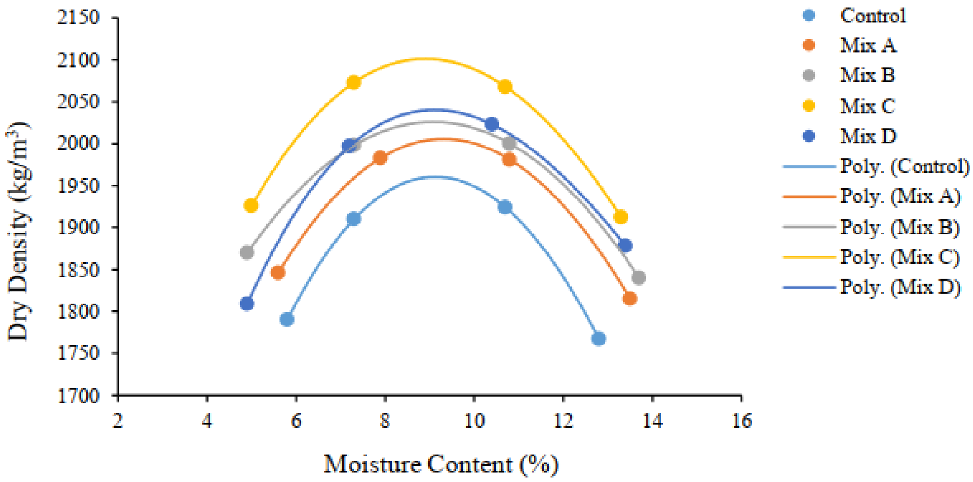

Figure 1 Compaction curve.

Table 6 displays the average value of the relationship between CBR and Maximum Dry Density. At 100% maximum dry density, the control mix showed a lower CBR value when compared to the design mixtures. Meanwhile, the addition of cement and SBA to the control mix showed an increased CBR value of 80.1% (DM-A), 86.9% (DM-B), 102.6% (DM-C), and 91.5% (DM-D). The Design Mix-C provides the highest CBR value of 102.6%.

Table 6 Average percent CBR at maximum dry density.

Mixture	Control Mix	Design Mix-A	Design Mix-B	Design Mix-C	Design Mix-D
Maximum Dry Density (kg/m^3)	1961	2005	2034	2101	2039
CBR (%)	28.6	80.1	86.9	102.6	91.5

Figure 2 presents the relationship between the average percentage of CBR values and the MDD of the proposed mixtures. It is evident from the figure that the % CBR and MDD values obtained from the compaction test of the design mixtures are higher than those of the control mixture. Notably, Design Mix-C stands out with the highest % CBR value compared to the other mixtures. One noteworthy observation is that increasing the proportion of SCBA (Stabilizing Binding Agent) added to the control mixture leads to both an increase in MDD and an increase in % CBR simultaneously. This suggests that the addition of SCBA enhances both the density and the bearing capacity of the material. These insights highlight the impact of SBA and cement content on the mechanical properties of the material, indicating their potential for improving the performance of the base coarse in construction applications.

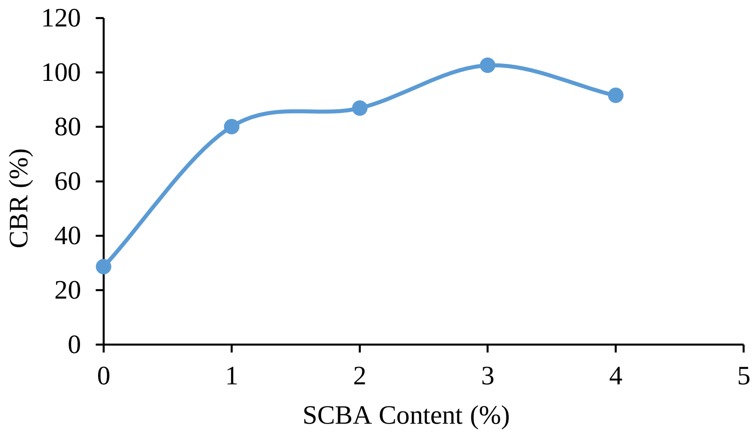

Figure 2 CBR values vs. SCBA content in m1ixtures.

The UCS value of the road mix base coarse using 100% crushed Mangima aggregate passed the minimum UCS value in Item 204 of DPWH Bluebook. Table 7 shows the average value of the Unconfined Compression Strength of the soil specimen. From the table, the design mixtures showed higher UCS values when compared to the control mix. Meanwhile, the addition of cement and SCBA to the control mix showed an increased UCS value of 269.8 psi (DM-A), 289.6 psi (DM-B), 319.4 psi (DM-C), and 265.6 psi (DM-D).

Table 7: UCS values.

Mixture	Control Mix	Design Mix-A	Design Mix-B	Design Mix-C	Design Mix-D
UCS (psi)	109.2	269.8	289.6	319.4	265.6

Figure 3 is a stress-strength diagram resulting from an UCS test of the five (5) proposed mixtures. This diagram illustrates the UCS values about the varying percentages of SCBA over 7 days. From the diagram, it's evident that the UCS values of the design mixtures surpass those of the control mixture. Notably, Design Mix-C stands out with the highest UCS value compared to the other mixtures. This indicates that Design Mix-C, with its specific combination of SCBA and other components, exhibits superior compressive strength characteristics compared to the other mixtures. These findings provide important insights into the effectiveness of different mixtures in achieving the desired mechanical properties for pavement construction. However, some limitations and challenges that are associated with the practical implementation of the study include its application generally for the specific regions where Mangima stone is available, the volume of the waste Mangima stone from the manufacturers of Mangima stone decorative, and the transportation of materials from the source to the production site.

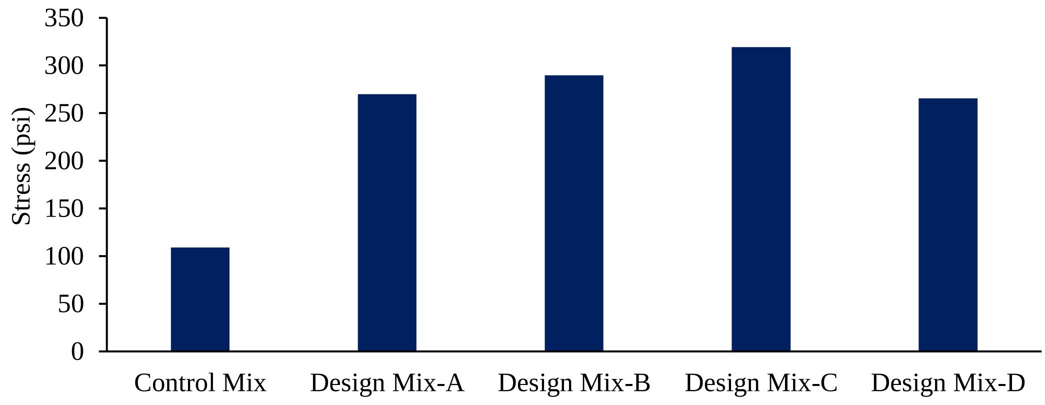

Figure 3 Stress diagram.

4. Conclusion

Based on the laboratory results, in comparison to the control mix, the design mixtures exhibited higher MDD and OMC values. This improvement in MDD and OMC can be attributed to the addition of cement and varying percentages of SCBA. Notably, Design Mix-C, consisting of 6% cement and 3% SCBA, demonstrated the highest MDD and OMC among the tested mixtures. Furthermore, Design Mix-C met the standard specifications outlined in item 204 of the DPWH Bluebook for the CBR result. This indicates that the combination of cement and SCBA effectively improved the soaked CBR value, making it compliant with the required specifications for the project. Moreover, the said mixture yielded the highest UCS value among all the tested mixtures. It exhibited superior compressive strength characteristics compared to the other mixtures, making it a promising choice for use in construction applications where high strength is required. Hence, the results of this study indicate that 100% Crushed Mangima aggregate replacement, combined with 6% cement and 3% Sugarcane Bagasse Ash, can indeed be considered a viable alternative coarse aggregate for road base applications. This mixture exhibits favorable characteristics and properties that make it suitable for use in road construction projects.

The following are the recommendations for future research and possible extensions of this study:

1. Evaluate the cost-effectiveness and environmental impact of the study;
2. Investigate the potential application of optimizing the SCBA, cement, and Mangima stone as materials in base coarse; and
3. Consider extending the curing period for the UCS tests from 7 days to 28 days using the same mixtures to provide insights into the long-term strength and performance characteristics of the materials, which may be particularly valuable for road construction applications where durability and resilience over time are critical factors.

5. Acknowledgements

We are grateful to the Faculty of Civil Engineering Department of the University of Science and Technology of Southern Philippines for their valuable time, constructive comments, and suggestions that have significantly enhanced the quality of this research study.

6. References

[1] Gidigasu MD. Characterization and use of tropical gravels for pavement construction in West Africa. Geotech Geol Eng. 1991;9(3-4):219-260.
[2] Nwakaire CM, Yap SP, Onn CC, Yuen CW, Ibrahim HA. Utilisation of recycled concrete aggregates for sustainable highway pavement applications: A review. Constr Build Mater. 2020;235:117444.
[3] Kelsey C. Bases and subbases for concrete pavement performance [Internet]. 2022 [cited 2023 Sept 15]. Available from https://www.geosynthetica.com/concrete-pavement-performance-bases-subbases/.
[4] Gonfa L, Quezon E, Geremew A. Experimental study on application of marble waste as conventional aggregate for base coarse materials. Journal of Civil Engineering, Science and Technology. 2020;11(2):144-163.
[5] Poernomo Y, Winarto S, Mahardana Z, Karisma D Ajiono R. The limestone as a materials combination of base coarse on the road pavement. IOP Conf Ser Mater Sci Eng. 2021;1125(1):012019.
[6] Dungca J, Florentino K, Dychangco T. Strength properties of road base materials blended with waste limestones. Int J GEOMATE. 2016;11(25):2493-2498.
[7] Broere P. Use of recycled aggregate - The best road base material [Internet]. 2017 [cited 2023 Nov 20]. Available from https://www.researchgate.net/publication/313106736_Use_of_recycled_aggregate_-_The_best_road_base_material.
[8] Batioja D. Evaluation of cement stabilization of a road base material in conjunction with full-depth reclamation in Huaquillas, Ecuador. Masters Thesis [Internet]. 2011 [cited 2023 Oct 20]. Available from https://www.researchgate.net/publication/326997881_Evaluation_of_cement_stabilization_of_a_road_base_material_in_conjunction_with_full-depth_reclamation_in_Huaquillas_Ecuador#fullTextFileContent.
[9] Bandara W, Mampearachchi W, Hewage S. Cement stabilized soil as a road base material for use in Sri Lankan roads. Eng J Inst Eng Sri Lanka. 2017;L(1):21-29.
[10] Dixon P. Factors affecting the strength of road base stabilized with cement slurry or dry cement in conjunction with full-depth reclamation [Dissertations]. Provo: Brigham Young University; 2011.
[11] Baghini M, Ismail A, Karim M, Shokri F, Firoozi A. Effect of styrene–butadiene copolymer latex on properties and durability of road base stabilized with Portland cement additive. Constr Build Mater. 2014;68:740-749.
[12] Ferguson E, Hoover J. Improvement of granular base coarse materials with Portland Cement [Internet]. 1965 [cited 2023 Nov 22]. Available from https://api.semanticscholar.org/CorpusID:130532938.
[13] Bhattacharja S, Bhatty J, Todres A. Stabilization of clay soils by Portland Cement or Lime - A critical review of literature. PCA R&D Serial No. 2066, Portland Cement Association, Skokie, Illinois USA. 2003.
[14] Kestler MA. Stabilization selection guide for aggregate- and native-surfaced low-volume roads. Washington, DC: USDA, Forest Service, National Technology & Development Program; 2009.
[15] Benhelal E, Zahedi G, Shamsaei E, Bahadori A. Global strategies and potentials to curb CO_2 emissions in cement industry. J Clean Prod. 2013;51:142-161.
[16] Devi BM, Chore HS. Feasibility study on bagasse ash as light weight material for road construction. Mater Today. 2020;27:1668–1673.
[17] Mulinari DR, Voorwald HC, Cioffi MH, da-Silva MP, da-Cruz TG, Saron C. Sugarcane bagasse cellulose/HDPE composites obtained by extrusion. Comp Sci Technol. 2009;69:214–219.
[18] Yadav S, Ray D. Utilization of sugarcane bagasse ash in bitumen. Int J Eng Res Technol. 2019;8(4):479-481.
[19] Sabat A. Utilization of bagasse ash and lime sludge for construction of flexible pavements in expansive soil areas, Electronic J Geo Eng. 2012;17:1037–1046.
[20] Hailu B. Bagasse ash as cement replacing material [Thesis]. Addis Ababa: Addis Ababa University; 2011.
[21] Rajkuman P, Krishnan K, Ravichandran P, Harini T. Study on the use of bagasse ash paver blocks in low volume traffic road pavement. Indian J Sci Technol. 2016;9(5):1-6.
[22] Zia A, Khan A. Effectiveness of bagasse ash for performance improvement of asphalt concrete pavements. SN Appl Sci. 2021;3(4):1-11.
[23] Tingson, T. Study on the stabilization of laterite soils as road base/subbase materials. Bureau of Research and Standards, Department of Public Works and Highways; 2017.
[24] Cabahug RR, Cabahug RG, Lamberte JCL, Neri AC. Mangima stone as alternative coarse aggregate in concrete. Mindanao J Sci Technol. 2011;9:19-28.
[25] Calibara JB, Cabahug RR. Effects of water-reducing admixture on the compressive strength of concrete using crushed Mangima stone as fine aggregate. Mindanao J Sci Technol. 2020;18(2):56-72.

[26] Getes E, Caingles V. Evaluation of the compressive strength of paver blocks with the inclusion of Mangima stone and Eggshell powder. Int J Health Sci. 2022;12044-12053.

[27] Simeon L. Bukidnon raises concerns over relaxing sugar imports [Internet]. 2019 [cited 2023 Nov 27]. Available from https://www.philstar.com/business/2019/01/29/1888895/bukidnon-raises-concerns-over-relaxing-sugarimports#:~:text=Bukidnon%20accounts%20for%2072%20percent,municipalities%20with%2011%2C395%20sugarcane%20farmers.

[28] Asgari MR, Dezfuli AB, Bayat M. Experimental study on stabilization of a low plasticity clayey soil with cement/lime. Arab J Sci. 2015;8(3):1439-1452.

[29] Nweke H, Okogbue CO. The potential of cement stabilized shale quarry dust for possible use as road foundation material. Int J Geo Eng. 2017;8(1):1-14.