Potential Use of River Sand in The Production of Artificial Coarse Aggregate Through Cold Bonded Granulation Technique

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ABSTRACT

The potential of sand as a primary material for coarse aggregate production has led to the development of Sand Artificial Coarse Aggregate (SACA), offering a sustainable alternative to natural aggregates. Utilizing locally available river sand, this approach enhances resource efficiency while mitigating environmental degradation from traditional quarrying practices. SACA is produced using a cold bonded granulation technique, which minimizes energy use and supports sustainable construction methods. This study explores the production and characterization of SACA with varying cement-to-sand ratios. Key properties, including density, water absorption, and compressive strength, were analysed for both SACA and concrete made with SACA. Among the samples, SACA E, with the highest cement content (35%), demonstrated the best performance, achieving a density of 1020 kg/m³, water absorption of 5.5%, and a compressive strength of 52.2 MPa under cube compression testing. Concrete incorporating SACA E exhibited structural integrity compliant with construction standards. These findings affirm the viability of SACA, particularly SACA E, as a substitute for traditional coarse aggregates, advancing sustainable construction practices.

Keywords: Sand Artificial Coarse Aggregate, Cold bonded, Sustainable construction

INTRODUCTION

Aggregates play a crucial role in the construction industry, particularly in concrete production, where they constitute 60–70% of the total volume [1]. The rising global demand for concrete, driven by urbanization and infrastructural expansion, has positioned the construction industry as one of the largest consumers of aggregates. However, this escalating demand has led to challenges such as resource overexploitation, supply constraints, and significant environmental impacts.

Rapid urbanization and industrialization have increased dependence on natural coarse aggregates, leading to resource depletion and environmental degradation. Quarrying activities, the primary source of coarse aggregates, contribute to deforestation, biodiversity loss, and pollution of air and water bodies, exacerbating climate change and disrupting ecosystems [2]. Malaysia faces severe ecological challenges due to uncontrolled aggregate consumption, with potential supply shortages on the horizon. Importing aggregates offers a temporary solution, but it is inefficient and costly due to fluctuating transportation expenses [3].

This research proposes the development of Sand Artificial Coarse Aggregate (SACA) using river sand to reduce reliance on natural coarse aggregates and promote sustainability. By employing the cold-bonded granulation technique, this study explores the potential of sand-based artificial aggregates as environmentally friendly construction materials, particularly in concrete production. River sand is abundant and commonly used in construction due to its availability and workability. It primarily consists of silica ($SiO2$) in the form of quartz, along with other minerals such as feldspar, clay, and organic materials [4]. Utilizing river sand in producing artificial aggregates not only addresses the depletion of natural coarse aggregates but also provides a sustainable solution for managing natural resources.

River sand is one of the most commonly used aggregates in concrete production and is widely available in most parts of the world. According to industry estimates, river sand accounts for more than 60% of the total sand used in concrete production worldwide [5]. Globally, the use of river sand in concrete production varies widely depending on the availability of resources and local construction practices. In some regions, such as Southeast Asia and parts of the Middle East, river sand accounts for over 90% of the total sand used in concrete production. In contrast, in some developed countries, such as the United States and Australia, the use of river sand in concrete production is relatively low, with alternative sources of sand, such as crushed rock and manufactured sand, being more commonly used [6]

The cold-bonded granulation technique has emerged as a promising method for producing artificial aggregates, diverging from traditional high-temperature processes. This technique involves the agglomeration of fine particles using a binder at ambient or slightly elevated temperatures. It boasts several advantages, including reduced energy consumption, diminished environmental impact, and the versatility to incorporate diverse raw materials, including waste streams. Bijen [7] and Ozturan [8] demonstrated that artificial aggregates produced through the cold-bonding process have a higher production rate compared to other methods. The cold-bonding process consumes less energy as it is carried out at ordinary temperatures and causes less secondary pollution since no gaseous emissions are involved.

MATERIALS AND METHODS

Preparation of samples

Production of Sand Artificial Coarse Aggregate (SACA).

The production of SACA was carried out using a disc pelletizer machine, as shown in Figure 1, which served as the primary equipment in the cold-bonded granulation technique. The disc pelletizer, used for the palletisation process, had a diameter of 150 cm, with the angle fixed at 45° and the rotational speed set to 38 rpm. Based on these parameters, approximately 5 kg of material was fed into the machine during each operating cycle.

Figure 1. Disc Pelletizer Machine

The raw materials used in the production of SACA primarily include sand, a binder (Ordinary Portland Cement), and water. The design mix proportions of SACA prepared using varying ratios of cement and sand, along with a constant water content (1.10 Kg) as shown in Table 1. Five samples (A, B, C, D, and E) are outlined, each with different percentages of cement and sand, which are adjusted to evaluate their impact on the properties of the coarse aggregate. The palletisation process of SACA is shown in Figure 2. The raw materials are mixed in a disc pelletizer to achieve a homogeneous mixture, and a certain amount of water is sprayed during the first 5 minutes to facilitate the formation of initial granules. Then the disc is continuously run for the generation and compaction of granulates. The total time used for one cycle is around 30 min with the size of production SACA is between 4.75mm and 12.5mm. After one cycle, the granulates SACA are collected and cured in sealed plastic film for 28 days for evaluating the physical and mechanical properties of the coarse aggregate. In addition, the mix proportion

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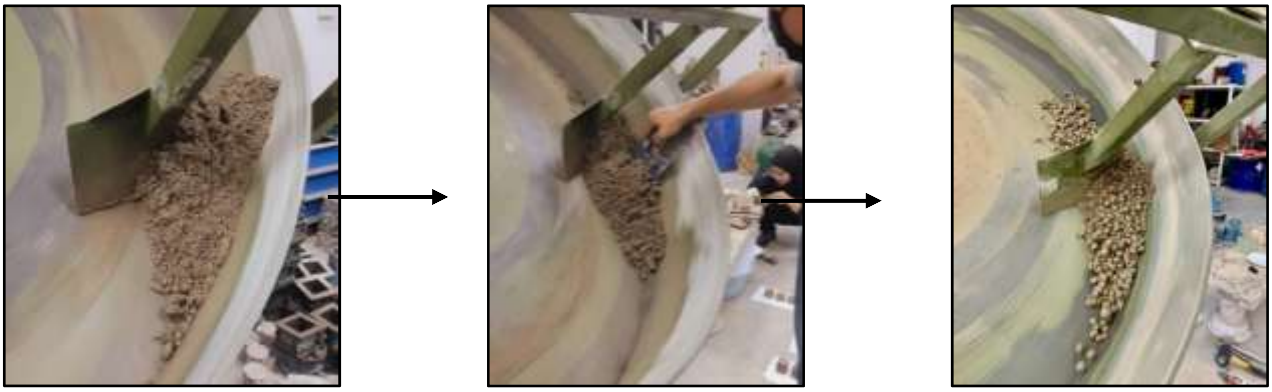
for each sample consist of one-fifth of the total mix to create a (50x50x50) mm cube. This been used for evaluate the strength of SACA as a replacement for the AIV and ACV tests.

Table 1. Designation of coarse aggregate

Samples	Percentage (%)		Weight (Kg)	
	Cement	Sand	Cement	Sand
A	15	85	0.75	4.25
B	20	80	1.00	4.00
C	25	75	1.25	3.75
D	30	70	1.50	3.50
E	35	65	1.75	3.25



(a) Sand + OPC + Water (b) Starts to form initial granules (c) Fully formed granules

Figure 2. Palletization process of SACA

Production of concrete

Mix proportion for concrete as shown in Table 2. Mixing of concrete in manual and casting it into a (100x100x100) mm cube, using SACA as the coarse aggregate component as shown in Figure 3. A step-by-step procedure is carried out to ensure thorough incorporation of SACA into the concrete mix, followed by moulding and curing for 28 days to produce standardized test specimens for evaluating the physical and mechanical properties of the concrete.

Table 2. Mix design of concrete

Aggregate Samples	**Concrete Sample**	**Ratio of mix design**			
		1	**2**	**4**	**0.85**
		Cement	**Fine aggregate**	**Coarse aggregate**	**Water/cement ratio**
		Mass (Kg)			
SACA A	C1	1	2	4	0.85

SACA B	C2				
SACA C	C3				
SACA D	C4				
SACA E	C5				

(a) Cement + Sand + SACA (b) Sand + Cement + SACA + Water (c) Mix casting into Cube

Figure 3. The process of mixing concrete and casting into the cube

Testing of samples

Density Test.

In this study, density will be measured for SACA, and the concrete made with SACA to assess how the substitution of artificial coarse aggregate influences the density and subsequent structural properties of the concrete. The density testing will follow the procedures outlined in ASTM C138/C138M [9] for concrete and ASTM C29/C29M [10] for aggregates.

Water Absorption Test.

Water absorption refers to the ability of a material to absorb and retain water, which is a crucial factor in assessing the durability, workability, and long-term performance of concrete mixes. High water absorption typically indicates increased porosity, which can weaken the concrete matrix, reduce its durability, and make it more susceptible to deterioration, such as freeze-thaw damage and chemical attacks. In this study, water absorption will be tested on the SACA and the concrete made with SACA, following the procedures outlined in ASTM C642 [11] to evaluate the impact of using artificial coarse aggregate on the material's porosity and durability.

Compressive Strength.

The compressive strength test is a fundamental mechanical test used to assess the ability of a material to withstand axial compressive loads without failure. In this test, a specimen of the material, typically in the form of a cube, is subjected to a gradually applied compressive force until it fractures or undergoes significant deformation. The compressive strength test serves as a crucial method for characterizing the mechanical performance of SACA and the concrete made from SACA. Conducting the compressive strength test involves preparing cube specimens of both SACA (50 x 50 x 50 mm) and SACA concrete (100 x 100 x 100 mm) according to specified dimensions and compaction methods. The testing is referred to MS EN 12390-3, 2012 [12].

While this method deviates from the standard approaches for assessing aggregate strength, such as the Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV) tests, it was chosen to observe the general trend of strength development as the cement content increased. The primary objective of this testing was not to achieve standardized results but to investigate the relationship between cement content and the compressive strength of the aggregates.

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RESULT AND DISCUSSION

Density

The Figure 4 presents the results of the density test for SACA and the corresponding concrete produced using SACA as coarse aggregate. The only difference in density within the SACA samples is brought about by the percentage of cement and sand in the mix. Since cement is denser than sand, as the percentage of cement increases and that of sand decreases, the density of the aggregate increases. This can be shown by the fact that SACA E has the highest percentage of cement at 35%, and the lowest sand content at 65%, making it the densest among the SACA samples. Other than that, poor compaction of concrete Sample E most probably caused voids and incomplete filling of moulds, which reduced the density of the concrete. In this mix, the water-cement ratio was low; this increases the cement content but decreases the amount of water available for compaction and hence makes the mix difficult to compact. Further, the lower content of sand contributed to an increase in the proportion of larger aggregates which might have caused more pronounced formation of voids, hence decreasing the density of concrete.

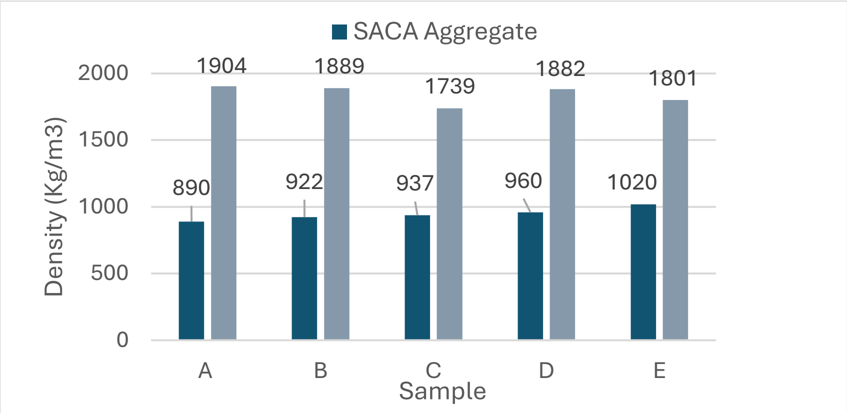

Figure 4. Density SACA aggregate and SACA concrete

Water Absorption

The water absorption test results, as shown in Figure 5, indicated that as the cement content increased, the water absorption of both SACA and the corresponding concrete decreased. This trend can be attributed to the higher cement content, which reduces porosity and improves the bond between aggregates, thereby densifying the microstructure. Sample A exhibited the highest water absorption for both SACA and concrete, with values of 8.6% and 12.1%, respectively. In contrast, Sample E, which contained the highest cement content, showed lower absorption values of 5.5% for SACA and 9.6% for concrete. These findings highlight the significant impact of mix proportions on water absorption and, more broadly, on material performance.

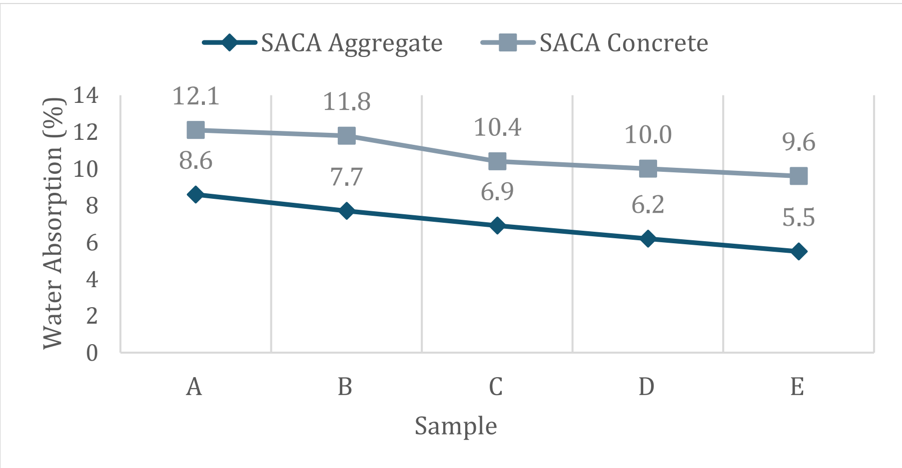

Figure 5. Water absorption SACA aggregate and SACA concrete

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Compressive Strength

The compressive strength test results, as shown in Figure 6, demonstrate that increasing the cement content significantly enhances the strength of both SACA and SACA concrete. For SACA, the compressive strength increased from 11.8 MPa for Sample A to 52.2 MPa for Sample E, indicating that a higher cement proportion improves the aggregate quality by reducing porosity. In the case of SACA concrete, the compressive strength also increased from 9.3 MPa for Sample A to 18.3 MPa for Sample E. However, the strength of SACA concrete is lower than that of the SACA aggregate alone, which can be attributed to the shape of the SACA. While SACA aggregates are granular and irregular, providing localized strength during compression, the SACA cubes used in compressive strength tests (50 × 50 × 50 mm) have a more consolidated structure that supports higher stress more effectively. Additionally, sample E achieved a compressive strength of 18.3 MPa and a density of 1801 kg/m³, which can be classified as lightweight concrete, as defined by the American Concrete Institute (ACI) 213R (2014) [13].

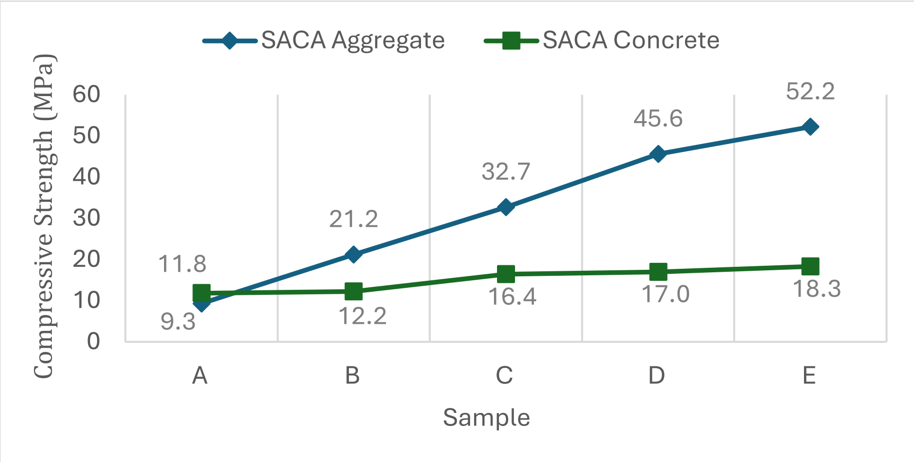

Figure 6. Compressive strength SACA aggregate and SACA concrete

CONCLUSION

This study highlights the feasibility of producing SACA through the cold-bonded granulation technique as a sustainable alternative to natural coarse aggregates. The composition of cement and sand significantly influences the physical, mechanical, and durability properties of concrete. Among the tested samples, SACA E, with its higher cement content, exhibited superior performance, including a denser microstructure, lower water absorption, higher density, and greater compressive strength, making it comparable to natural aggregate-based concrete. This suggests that SACA E can effectively replace natural coarse aggregates in concrete production, contributing to resource conservation and sustainable construction practices. Future studies should explore further optimization of SACA composition and evaluate its long-term performance under varying environmental conditions.

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