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Mechanical Properties of Synthetic Lightweight Coarse Aggregate Infuse with Offshore Sand

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ABSTRACT

Alternative replacement for land aggregate is very important for island and coastal region where land aggregate resources is scarce, expensive and even unavailable for construction industries. For country that have limited sources of land aggregate, offshore sand is a potential choice of replacement for their construction industries. This research studied the production and usage of synthetic lightweight coarse aggregate produced using offshore sand (SYLCAG). SYLCAG was produced to replace coarse aggregate that normally use igneous rock for concrete production. It was produced with density of 1300 kg/m^3 which is nearly 60% lighter than normal aggregate. This SYLCAG was used as a full replacement for coarse aggregate in concrete which then produced as a concrete with density almost 1900 kg/m^3. The produced concrete did not have achieve the design strength of 25 MPa concrete using the standard concrete design. However, it still has the potential to be develop with higher design and later used as structural concrete.

Keywords:
Synthetic aggregate; lightweight aggregate; offshore sand; alternative concrete

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1. Introduction

Consumption of natural land resources as the prime construction materials has never stopped to be an issue for construction industry worldwide. Continuous growth of population increases the demand for building and infrastructure for most countries. Shortage of natural construction materials to provide the high demand have made the construction industry cost surge rapidly. Inadequacy of construction materials may become a major concern in the near future as it is imminent with the progressing of the industry [2]. This include concrete which use aggregate which are gather from natural land resources. In the near decades, the demand of aggregates is predicted to be double with the current growth development [3]. The natural resource consumption mostly occurred in continuously growing countries which include for example China, India, and other various countries [2]. Malaysia apparently as developing country have reported to import aggregate 6.3 times higher

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in 2008 compared from the previous years when there was 2% shortage of granite and limestone aggregate production [4].

In 2010, Malaysia consumed 2.76 billion metric tons of natural aggregate that include the usage for construction industries where most of the sand and gravel produced were from alluvial, glaciofluvial, or marine origin [5]. With the last decade progression, it is unavoidable that exploration for other sources is necessary not with the aim to further exploit natural resource but for reservation of future development other than relying on recycling activity. Offshore sand is one of already accessible natural resource that have been used for land reclamation and has potential to be use in materials production for construction industries. Utilizing offshore sand in concrete production is a prospective alternative to ease land resources depletion and also construction cost particularly for near coast areas [6].

Previous studies have found that river sand can be replaced in concrete and mortar with other various type of sand which include offshore sand. These studies provide evidence that offshore sand can be use as substituted for river sand in concrete and mortar [7-11]. The use of offshore sand in concrete was limited by the properties of the materials itself where the chloride content level is not suitable for concrete. With a high level of chloride content, the materials will act as a mechanism that will enhance the corrosion rate in reinforced concrete. There are many ways that can be used to treat the offshore sand so that the chloride content will be reduce to an acceptable level. One of the studies found that offshore sand can be treated with gravity drain so that the content of Cl^- ions could be reduced to an acceptable level for OPC concrete mix [7]. They stated that a conservative limit for allowable Cl^- ions in offshore sand for OPC based reinforced concrete is 0.075% by weight of the sand. The study [7] also found that the concrete mix using offshore sand (Cl^- content of 0.075%) and designed as grade 20, showed the satisfactory and similar corrosion performance in embedded steel to a chloride free control mix. It shows that offshore sand is capable to replace washed sand in any conventional OPC concrete mix that should include foamed concrete.

This paper presents an explorative study which produced offshore sand foam concrete later crushed to synthetic lightweight coarse aggregate (SYLCAG). It was indicated by previous studies [12-17] that recycle crushed materials can be used to replace original natural aggregate to be produced into new concrete. It was discovered that using crushed concrete as aggregate can produce a concrete with similar bulk engineering and durability properties as the corresponding natural aggregate concretes, providing they can be designed to have equal strength [12]. However, it was found the fresh and mechanical properties of recycle aggregate concrete appears to be marginally inferior from normal concrete but can be improved by suitable surface treatment of the used recycled aggregate [13]. This study demonstrates the idea of integrating washed offshore sand into synthetic coarse lightweight aggregate to help in reducing the usage of natural raw rocks aggregate and decrease the bulk weight of a concrete mix.

2. Methodology

2.1 Materials

This study was conducted by using the offshore sand that was taken from reclamation project at Pantai Klebang, Melaka. Land reclamation has been done for decades in Melaka by the state government. Almost all the sand was pump from the states offshore itself. A large quantity of sand was taken from a single area of reclamation to control the properties of this sand. The offshore sand taken is known has never been treated to reduce their natural sea content but was already exposed to land weather for more than 3 years or higher. Although it has been exposed for a long time to rain and sun for a long time, the chloride content of this sand was found higher compared to river sand sample that will be discussed in later part. This sand was used as it was taken to produce a foam concrete.

With ability to control the density of foam concrete, offshore sand with the size lower than 2 mm was used as the fine aggregate in a design with density of 1300 kg/m^3 (SYLCAG1300) and 1600 kg/m^3 (SYLCAG1600). After water curing for more than 28 days, the foam concrete was crushed. With a sieving process, it was produced into SYLCAG with size of 2.36 – 20 mm. This SYLCAG have gone through several test to determine the important properties required for application as a coarse aggregate.

2.2 Tests

The tests that were conducted for this study was divided into two phases. These two phases were conduct for the materials itself and for the product of concrete. The initial phase includes all test to study the physical properties of the produced SYLCAG. The tests consist of chloride content test, abrasion test, crushing value test and compressive strength test. The latter phase of the study was conducted to obtain the compression and flexural strength of the concrete that were produced by using SYLCAG.

The concrete that uses both SYLCAG were designed based on normal mix for concrete with target strength of 35 MPa and were labels as G35. From G35 design, replacements were made based on volume replacement and were named SC1300 and SC1600 respectively. These designs were aimed to produce modified concrete using SYLCAG with the same volume but lower densities. Details of the mix design for 1 m^3 is shown in Table 1. All concrete were designed using the same weight of cement and water. The weight of cement that was used was 420 kg while the weight of water was 210 kg. Samples for compression test were produced as cube samples with the size of 150 mm. The flexural test was conducted using samples with the size of 750 x 150 x 150 mm. All samples were cured for 7 days, 14 days, and 28 days.

Table 1
Detail of mix design

Sample Mix	Coarse Aggregate (kg)
G35	1150.5
SC1300	604
SC1600	767

3. Results and Discussion

3.1 Chloride Content

Table 2 shows the chloride content in all types of samples. These Chloride content test result prove that the offshore sand obtained from the land reclamation still have high content of chloride ion even after exposed for a long time on land. From result, offshore sand that used as a sample have chloride content of 133 mg/L which is higher than river sand that only have 48 mg/L. Nevertheless, SYLCAG that was produced from the same offshore sand was tested later and was found with reduced chloride ion even without treatment of the offshore sand. From the test conducted, SYLCAG that produced with density of 1300 kg/m^3 have a low chloride content which was only 7 mg/L while the other which produced with density of 1600kg/m3 also have a low chloride content of 10 mg/L, which is acceptably low compared to the sand as land aggregate commonly used for concrete.

Table 2
Chloride content of samples

Sample	Chloride Content (mg/L)
Sand	48
Offshore Sand	133
SYLCAG1300	7
SYLCAG1600	10

The main reason of this reduction was due to the effect from producing SYLCAG with foaming agent and the curing process later. The cube sample was soaked in the water for 28 days. This result show that processed offshore sand product can have a lower chloride content. With this lower chloride content, SYLCAG can be used in concrete as it achieved a lower value compared to normal river sand that was used for concrete mix.

It was highlighted by many that higher chloride content may speed the corrosion process happen. Specify in British Standard that the most commonly used limit for total chlorides is the 0.4% limit by weight of cement. For SYLCAG1300, with the weight of 650 kg of SYLCAG, the chloride weight was only 3.5 gram which was very low compared to weight of cement.

3.2 Abrasion Resistance and Aggregate Crushing Value

In the process of transporting and stockpiling of coarse aggregate before used as concrete mix materials, the materials will normally be subjected to wearing which will affect the aggregate surface area. Abrasion resistant test was conducted to determine the suitability of SYLCAG for application if subjected to wearing at certain level. Table 3 shows the comparison between normal aggregate, SYLCAG1300 and SYLCAG1600 on abrasion resistant. The test was conduct for the size of aggregate between 10 to 19 mm. The angularity of aggregate was acceptable in standard use. The initial weight was divided to 2500 g for size from 10 to 14 mm and another half for size from 14 to 19 mm.

Table 3
Abrasion resistance of aggregates

Sample	Weight of sample (after) (g)	Weight loss (g)	Loss
Normal aggregate	3610	1390	27.8 %
SYLCAG1300	2630	2370	47.4 %
SYLCAG1600	2700	2300	46.0%

From the results, both SYLCAG was verified with low abrasion resistance. Referring to American Society for Testing and Materials (ASTM), the allowable abrasion value that can be used for concrete should be less than 45%. For these mixes, some modification on the SYLCAG design mix can be done to achieve that limit because the percentage of loss for the produced SYLCAG was not too far from the limit. The surfaces of SYLCAG basically are full of voids which produced unsmooth surface of the aggregate itself. If the numbers of surface voids can be reduced there are high prospect to increase the abrasion resistance.

The aggregate crushing value also one of important properties of aggregate that need to be determine. It provides a relative measure of resistance toward crushing under gradually applied load. Normally the allowable crushing value for aggregate is between 25% and 35% which depend on the application of the aggregate. Table 4 shows the comparison between normal aggregate and SYLCAG crushing value. With limit of 30 % for crushing value, SYLCAG was recorded to reach less than 40% which was not far greater than 30%. Its show that there is promising possibility for the mix to be modified to achieve the limit of 30%.

Table 4
Aggregates crushing value

Sample	**Aggregate Size** (mm)	**Weight of Sample** (g)			**Loss**
		Before	After	Loss	
Normal aggregate	14-10mm	2680	2050	630	23.51%
SYLCAG1300		1580	987	593	37.53%
SYLCAG1600		1600	1067	533	33.31%

3.4 Aggregate Compressive Strength

Aggregate compressive strength was determined in order to verify the self-strength of SYLCAG before incorporated in the concrete mix design. The normal nature coarse aggregate like granite has the strength that is more than 100 MPa which is very high toward the end only used to produce normal concrete with strength that is less 60 MPa. Fig. 1 shows the relation between compressive strength and curing age. From the graph, the compressive strength increase is proportional to curing age. For this mix design of foam concrete, the compressive strength keeps increased until 28-days. The result for compressive strength for SYLCAG achieved expectation which higher than 5 MPa for 28-days. The minimum compressive strength that has been setup was 5.0 MPa. The study proceeds with this mix design to produce lightweight aggregate. Compressive strength of foam concrete influenced by many factors such as age, curing method, density and mix proportion. Other parameters that affect the strength of the foam concrete are cement sand and water cement ratio, curing regime, size and type of sand and type of foaming agent used [18,19].

3.5 Lightweight Concrete using SYLCAG

The most important properties of hardened concrete that need to be apprehended is a good compressive strength. Normally the minimum strength that are used in structure is more than 20 MPa. As mentioned in method earlier, groups of samples were produced to determine the compressive strength. The test was carried out on cube samples which undergone curing for 28 days. Generally, the compressive strength of all concrete increased with the curing age. Fig. 2 shows the chart of compressive strength between normal concrete G35 with modified design using SLYCAG. From the chart, we can see the huge different between normal concretes with SYLCAG concretes.

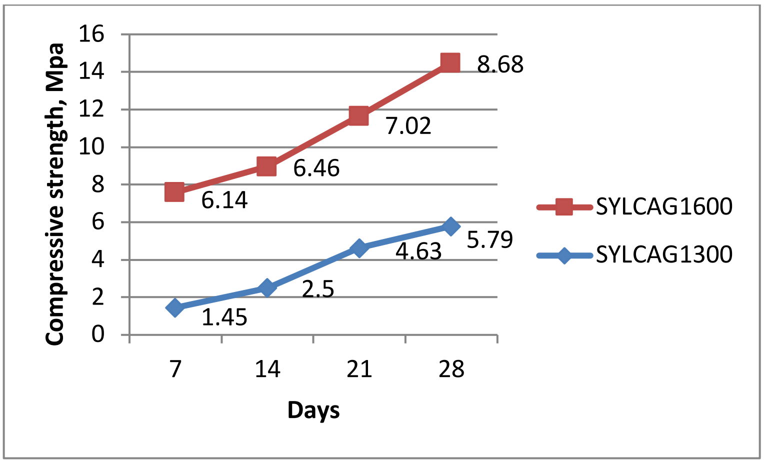

Fig. 1. Compressive strength of SYLCAG

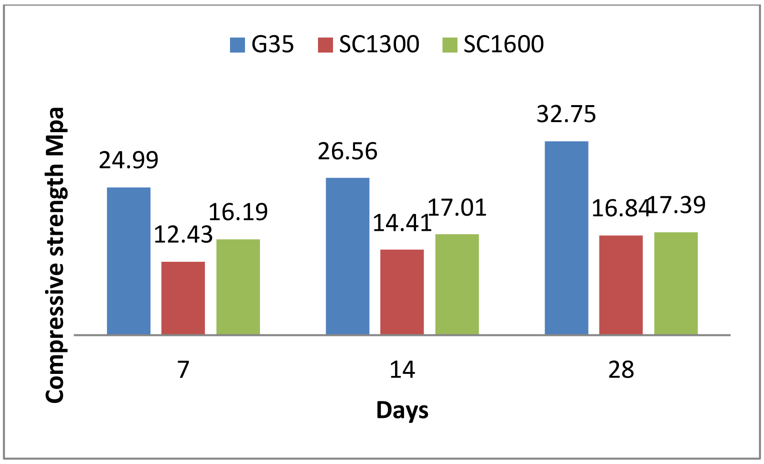

Fig. 2. Compressive strength of samples

For three sets of days, the normal concrete has far higher compressive strength compare SYLCAG concretes. The minimum compressive strength that was aimed for these two mixes was 20 MPa. However, with a design of G35 around 17 MPa was achieved by both designs. It is expected that if a design with strength of 45 to 55 MPa is used, there are promising possibility that 20 MPa strength can be achieved by using SYLCAG with density of 1300 kg/m^3 and 1600 kg/m^3.

Table 5
Properties of concrete achieved at 28 days

Sample	Density (kg/m^3)	Compressive strength (MPa)	Flexural strength (MPa)
G35	2296.30	32.75	4.21
SC1300	1930.86	16.84	1.54
SC1600	2068.15	17.39	2.04

While having a low strength compared to normal concrete design, SYCAG concretes has the advantage with its much lighter and lower density as recorded in Table 5. Highlighted in this study also when SYLCAG was produced with a very low strength as shown in Fig. 1 earlier, SYLCAG was able used to produce concrete with strength that is more than 15 MPa in this study.

It is a fact for foam concrete, the strength will be reduced because of high number of voids developed in the concrete itself. But by producing initial aggregate with void (SYLCAG), the void was controlled in the coarse aggregate only. With this void, flexural stress capacity also was reduced as shown in Table 5. But this property of concrete is normally replaced with reinforcement if the concrete is used in structure application. With further experimental design, the compressive and flexural strength at 28 days for SYLCAG concrete can be improved with the aim to keep the density below 2000 kg/m^3.

4. Conclusion

This study on lightweight coarse aggregate using offshore sand (SYLCAG) has found another opportunity to apply offshore sand in the concrete industry. However, with limited finding of this study, more improvements of design need to be achieved to validate its usage for structural concrete. The SYLCAG concrete need to be test as reinforced structure concrete to serve this purpose. It is also important to achieve a good compressive strength design first which have strength that is more than 20 MPa but have low density. This strength also needs to be combine with a low density product to make it more relevant in the industries. If this design is available, this SYLCAG have high potential for usage in countries that have low natural aggregate storage. There works that prove that foam concrete was used to produced high strength concrete [20].

SYLCAG also have been produced with prove that the chloride content is no concern anymore toward application in reinforced concrete. Nevertheless, it is required to certify this with more study with long term effect toward corrosion potential if SYLCAG is used to produce reinforced concrete structure. It is because even with low chloride content, the void in the aggregate can contribute toward reinforced concrete deteriorations.

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