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Structural Performance Assessment of High Strength Concrete Containing Spent Garnet under Three Point Bending Test

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Abstract. The utilization of river sand for miscellaneous construction purposes had directly increased due to rapid growth of construction industry. This fact caused over exploitation of riverbeds and troubled the eco-system. This study aims to find out the optimum percentage of spent garnet in high strength concrete and to forecast the structural performance of high strength concrete containing spent garnet with the previous research results. This study focusing on comparing and forecasting the utilization of 0%, 10%, 20%, 30% and 40% spent garnet as a sand replacement in high strength concrete at the age of 28 days. The level of 20% replacement of sand seen to be the optimum percentage of spent garnet for this concrete mixture to enhance its structure performance. It is concluded that, utilization of spent garnet in high strength concrete production able to reduce the dependency on river sand and lesser the waste from landfill.

1. Introduction

Nowadays, high speed growth of construction industry has depleted a great quantity of natural resources such as sand and gravel to produce building materials. Concretes being consumed in billions of tons each year in this world, second only to water. [1]. In order to supply the increasing demand from the construction industry, many country especially China has executed a large scale of stream sand and rock mining since the mid-1980s [2]. This human activity has over-exploited the river beds and leads to a series of serious problems. Thus, there is a necessary in utilizing of other waste materials as sand replacement in high strength concrete to maintain the sustainable construction within the industry.

Concrete is one of the major construction materials and broadly utilized for structural constructions such as buildings, factories, dams, bridges, tunnels, pavement and etc. Different ratio of cement, water, sand and coarse aggregate produce different performance of concrete. At the most standards nowadays, high strength concrete can reach the compressive strength of more than 50 MPa [3]. Generally, a concrete was designed to resist the compression meanwhile the reinforcement was designed to transfer tension stress in the concrete structure. The flexural strength and compression strength of beam should be designed to be higher as it is one of the primary elements to resist the structure imposed load in the building. The excessive concrete beam deflection lead to destruction on the other structural parts of the building.

Garnet is a useful mineral in industrial uses like abrasive blasting media, abrasive powders, water jet cutting, water filtration granules and so on. A great amount of garnets were imported in Malaysia shipyard industry, there was 2000 tons of garnet being imported from Australia [4]. It can be reused 3 to 5 times only to keep it entire performance perfect [5]. After that, its performance degrade to a lower level and cannot be reused again in the abrasive blasting process. During that time, it been removed and called "spent garnet" [4]. During the process, spent garnet sand is generated as a by-product. It is categorized as a solid waste and dumped in the landfill which reduce the land space and raise the environmental issues.

Hence, there is an absolute necessity to identify a sustainable construction material, such as spent garnet to replace the river sand. In this study, spent garnet was used as fine aggregate replacement in the high strength concrete. The possibility of reusing spent garnet as sand replacement would potentially enhance the strength and even the structural performance of the high strength concrete. This substitution might produce environmental friendly construction material, decrease the relying on river sand for concrete production and also reduce the landfill problems. The investigation of spent garnet is not only to attain sustainability and reduce environment pressure, but simultaneously to improve the structural properties of the high strength concrete.

2. Materials and methods

2.1. Materials

According to BS EN 1008: 2002 [6], mixing water for concrete must consist of pH value greater than 4. Impurities of water cause concrete to be difficult to harden and reach required strength. High strength concrete usually made using a lower water cement ratio. The water cement ratio is ranging between 0.25 to 0.35 was used.

Cement acts as the binder in the concrete. The combination of water and cement form a cement paste that can bind the aggregates and cement to produce the concrete. In this study, Ordinary Portland Cement (OPC) chosen to produce high strength concrete.

Aggregates can be separated into two types, which are fine aggregates and coarse aggregates. In this study, crushed stone with maximum size of 20 mm diameter was used whilst fine aggregates used having the size to pass through 5 mm sieve. Both of this aggregates size were the commonly used dimension in the construction industry.

Spent garnet was used as sand replacement in the high strength concrete. Sample of spent garnet shown in Figure 1. It obtained from the Malaysia Marine and Heavy Engineering Holdings Berhad (MMHE) which located at Pasir Gudang, Johor. Before concreting, it has been sieved to pass through a 5 mm sieve as similar to the sieving procedure of fine aggregates.

Figure 1: sample of spent garnet

The steel bar type used was high yield steel with characteristic of 500 N/mm^2 for main reinforcement whilst 250 N/mm^2 for the stirrups. The main reinforcement have a diameter of 10 mm while stirrups have a diameter of 6 mm.

Chemical admixture normally added to high strength concrete mix to enhance its workability. It complied with the standard of BS 5075: Part 1:1982 [7]. Under general circumstances, the dosage of this superplasticizer shall be 0.6% - 1.2% of the total amount of cement content. The dosage rate should not exceed 2.5 L per every 50 kg of cement.

2.2. Mix proportions

In this study, concrete Grade 60 determined through the Department of Environment (DOE) method. The concrete mix design proportion for 0%, 10%, 20%, 30% and 40% of spent garnet by weight as partial sand replacement were denoted by C0, C10, C20, C30 and C40 respectively as shown in Table 1.

Table 1. Mix proportions (per m^3)

Mixes	Cement (kg)	Water (kg)	Fine Aggregates (kg)	Spent Garnet (kg)	Coarse Aggregates (kg)
C0	457.14	160	445.72	0.00	1337.14
C10	457.14	160	401.15	44.57	1337.14
C20	457.14	160	356.58	89.14	1337.14
C30	457.14	160	31.200	133.72	1337.14
C40	457.14	160	267.43	178.29	1337.14

2.3. Experiment methods

2.3.1. Sieve analysis

The test was to evaluate the particles size distribution according to (BS 410: 1986) [8]. There were 2 kg of sand and spent garnet prepared respectively. The sand was dried to a constant mass at a temperature of 110˚C ± 5˚C. The sand was placed in mechanical shaker which had arranged according to progressive size. The sand was sieved by mechanical shaker for 5 minutes. The sand retained for each sieve plate were weighted and recorded. Whole procedures were repeated for spent garnet. Fineness modulus values of the samples were calculated.

2.3.2. Slump test

The test was conducted to determine the workability in the concrete mix according to (BS EN 12350 – 2: 2019) [9]. The fresh concrete mix should compact into a cone in three layers (each layer approximately one – third of the cone height) and each layer compact with a tamping rod of 16 mm in diameter by 25 times. When the cone was lifting upward steadily, the distance of slumped concrete provided a measure of concrete consistency. Each concrete design proportion have it slump testing to determine their workability.

2.3.3. Compressive strength test

The test was to determine the optimum percentage of spent garnet in high strength concrete according to (BS EN 12390 – 3: 2019) [10]. The cube dimension is 100 mm x 100 mm x 100 mm. The mould of concrete cube was removed on the next day of casting. The cubes were then immersed in the water tank to carry out curing process. The test was carried out to cube specimens at the concrete age of 28 days by using the Compression Testing Machine (CTM). All of the concrete mix have their compression test respectively.

2.3.4. Three point bending test

The test was performed to determine the load deflection pattern and ultimate axial load according to (BS EN 12390 – 5: 2019) [11]. Moreover, this testing can be determined the failure mode of the beam specimens. The proposed beam dimension was 120 mm (width) x 150 mm (height) x 800 mm (length).

It is curing for 28 days before testing. The test carried out by using Universal Testing Machine. The beam specimens were subjected to a bending moment by the application of the load throughout upper and lower rollers. The arrangements of loading must consist of one load applying roller at mid span of the beam. The maximum loading sustained was recorded, then, the flexural strength was calculated. All of the designed concrete proportions undergo this testing.

3. Results and discussion

This part presents finding of this study, comparison and some predictions were carried out based on previous researches to forecast the spent garnet optimum percentages and the structural performance of high strength concrete.

3.1. Sieve analysis results

Particles size determination was important as it determined the effectiveness of the final product. Fineness modulus provided a way to quantify the average size of aggregate in most of the concrete mix.

The fineness modulus value for sand was 4.67. Figure 2 shows the sieve analysis grading curve for sand. The sieve analysis grading showed most of the sand particles have similar size.

The fineness modulus value for spent garnet was 4.65. Figure 3 showed the sieve analysis grading curve for spent garnet. The grading curve indicates most of the spent garnet particles have same size. The grading curve for both sand and spent garnet showed a high similarity. Both fineness modulus values were very closer, only different in 0.02. Therefore, spent garnet can be used for sand replacement testing in concrete.

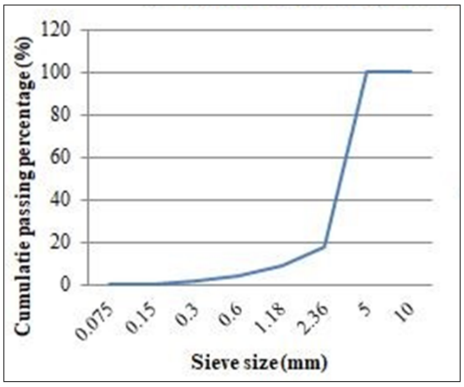

Figure 2. Sieve analysis grading curve for sand

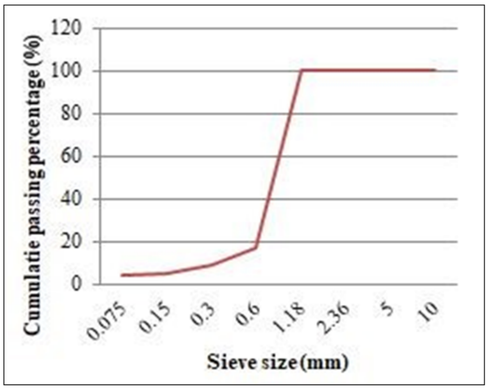

Figure 3. Sieve analysis grading curve for spent garnet

3.2. Slump test

Both Table 2 and Table 3 were the slump test results review from the previous researches. In this study, the concrete type was high strength concrete mixing with spent garnet. Generally, the workability of high strength concrete was lower than normal strength concrete. Smaller particles size of spent garnet improve the workability of concrete as the surface bonding between particles are increasing.

Table 2. Slump test result on spent garnet as sand replacement

Type of Concrete	Type of Replacement	Findings
Self-compacting geopolymer concrete	Sand replaced by spent garnet	Increasing of spent garnet enhance the workability as spent garnet consists of more fine particles than sand [5].

Table 3. Slump test result on high strength concrete

Type of Concrete	Type of Replacement	Findings
High strength concrete	Sand replaced by crumb rubber	Slump results showed good workability with recommended superplasticizer ratio [12].
High strength concrete	Sand replaced by coal bottom ash and oil-palm boiler clinker	When CBA or OPBC is replaced the fine aggregate, the workability of the concrete not much different [13].

Therefore, based on these results, the workability of high strength concrete containing spent garnet was increasing with the higher percentages of sand replacement.

3.3. *Compression strength*
In this study, control mix was tested for compression strength at the concrete age of 7 days. The average compressive strength was 60 MPa which had exceed the target strength of 39 MPa (at 7 days, 65% of full strength).

Based on previous research results [4,5,13-15] shown in Figure 4, the maximum concrete compressive strength only can be achieved at a range of 10% to 25% of sand replacement. This mean that if the sand replacement percentages exceed the range, it brought negative effect to the concrete compressive strength.

Therefore, according to the summary of previous researches, and the initial testing for this work it is revealed that 20% of spent garnet as sand replacement in high strength concrete could achieve the optimum compressive strength at 28 days.

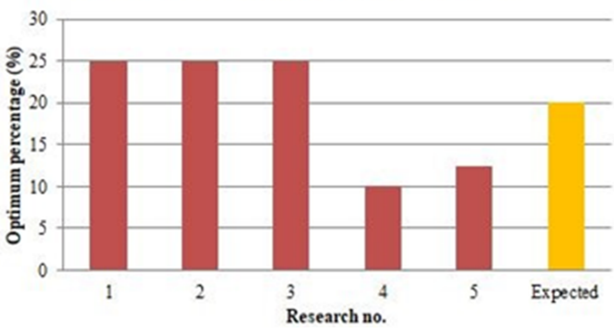

Figure 4. Previous research results versus expected results on compression test

3.4. *Structural performance prediction*
In this study, some prediction were carried out on structural performance of high strength concrete beam with referred to the previous research findings.

Figure 5 showed the comparison between the previous research results [5,12,15-16] and expected results in this study based on initial testing. From the previous research findings, it can be observed that most of the sand replacement were successfully improved the flexural strength of the beam. But, it can only achieved the optimum flexural strength at a range of 10% to 25% of sand replacement. Higher sand replacement percentages decrease the flexural strength of the beam.

Therefore, it was expected that 20% of spent garnet as sand replacement in high strength concrete gained the optimum flexural strength at 28 days in this study.

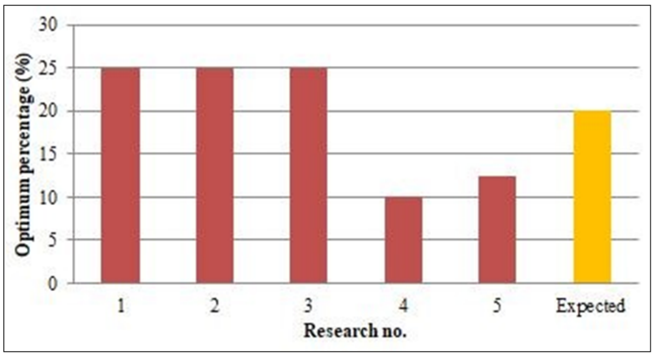

Figure 5. Previous research results versus expected results on flexural strength

3.5. Load-deflection curve

Generally, a deflection happen in structural members when there is a load exerted on it. In a study on fracture behavior of recycled aggregate concrete under three point bending. [17] found that when the replacement of recycled aggregate concrete is below 70%, the fracture toughness is remain the same. Besides that, in a study on the structural behavior of ultra-high performance fiber reinforced concrete-normal strength concrete or high strength concrete composite members [18], authors concluded that with the 1.5% and 2% of fiber content, the beam specimens had the highest ability to carry loading.

Therefore, it can be expected that the stiffness of reinforced high strength concrete beam was stronger with the 20% replacement of spent garnet to the river sand. It can be also concluded that a higher of loading are required for high strength concrete beam that containing 20% spent garnet to occur failure compare to the other testing samples.

4. Conclusion

It can be concluded that the replacement of sand by spent garnet improves the compressive strength of the concrete. The percentage of 20% spent garnet replacement seen to raise the compressive strength of the high strength concrete to the optimum. Besides that, strength of concrete with the optimum replacement percentages of waste material can improved the flexural strength of the concrete. Generally, the structural performance of the high strength concrete containing 20% of spent garnet improved. For further study, it is recommended to study the structural performance of high strength concrete beam containing spent garnet as replacement of sand by volume to explore the potential of higher replacement volumes.

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