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Effects of Spent Garnet on The Compressive and Flexural Strengths of Concrete

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Abstract: Sand is the non-renewable resource which has been over-exploited from rivers in sync with the rapid development of construction industries to produce concrete. This affected the morphology of rivers and interrupted the functionality of riverine ecosystems by pollution. Meanwhile, the unrecyclable spent garnets were disposed of on a large scale and led to waste pollution. Therefore, this study aimed to determine the compressive and flexural strengths of concrete consisting of spent garnet as sand replacement. The specimens were prepared with consisting of spent garnet as sand replacement by weight in 0%, 10%, 20%, 30% and 40%. They were tested under compressive strength test at the age of 7 and 28 days while flexural strength test was conducted on the 28days. The findings revealed that the workability of fresh concrete was enhanced by an incremental amount of spent garnet. However, the compressive and flexural strengths of concrete consisting of spent garnet were discerned to be lower than control samples at all levels of replacement. Overall, the replacement with 20% spent garnet showed the optimum compressive and flexural strengths. It is concluded that the usage of spent garnet is considered as a promising resource for reducing consumption of sand and thus, improving the environmental problems.

Keywords: Sand, Spent Garnet, Compressive Strength, Flexural Strength

1. Introduction

Many countries are in a rapid growing status especially in construction industries over these recent years. Accordingly, a huge amount of construction materials is exploited for concrete production. Sand is one of the constituent materials of concrete. It is claimed sand is the most mined natural resource globally, accounting for 79% of total extraction (28.6 giga tons per year). In 2010, the total consumption of sand and gravel in Malaysia was found to be 1.17 billion metric tons [1]. Due to the high demand of

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sand in concrete production, this inevitably draws the ever-increasing utilization of sand from rivers. Consequently, this human activity destroyed the rivers in ways such as raising in depth of riverbed, reducing water tables, increasing salinity, and followed by disrupting river embankments. In addition, the rivers are polluted by the impurities and thus destroy the aquatic life in the river [2].

Generally, sand is the fine aggregates in concrete which means the particles pass through sieve No.4 of 4.75 mm openings [3]. Sand serves several purposes in concrete. The role of sand acts as filler to increase the volume of concrete thereby reducing air void between coarse aggregates and generally beneficial in strengthening the concrete products [4]. The use of high density packing in concrete helps to reduce the quantity of cement used, which improves the mechanical and durability aspects of the concrete as well. The performance of concrete can be defined by the mix proportion of its composite materials in different ratios for cement, sand, aggregate and water.

Meanwhile, In Malaysia, Malaysian Marine Heavy Industry (MMHE) imported approximately two thousand tons of garnet in 2013 for sandblasting ship purposes [5]. The technique of abrasive blasting as preparing surfaces for coating and painting and it is used when there is need in the activities of ship maintenance, cleaning process, repairing work and construction of vessels. Garnet can be reused until it no longer offers its performance and degrades to an extent known as spent garnet. Therefore, a huge amount of spent garnet is discharged in landfill, pits, ocean, and streams. As a result, this causes environmental problems such as waste pollution.

Regarding these issues, it is important to reduce the pressure on the environment. In this study, spent garnet was used as the partial alternative material for sand in concrete. The purposes of this study were to determine the compressive and flexural strength of concrete consisting of spent garnet as sand replacement. The potential of spent garnet as sand replacement in concrete not only would reduce the consumption of sand but also improve the environmental issues by reusing the spent garnet. Thereby, this could enhance the green concrete technology and maintain the sustainability of the ecosystem.

2. Methodology

A few important strategies and techniques were emphasized in the methodology to achieve the objectives in this study. The experimental materials, mix proportions and laboratory tests were explained as below.

2.1 Experimental Materials

a. Cement

Cement primarily functioned to bind the concrete constituents together via hydraulic reaction with water. It was also necessary for filling spaces between aggregates and contributing to the composite's strength. According to ASTM C150 [6], type I - Ordinary Portland Cement (OPC) was used. It was the ordinary general purpose Portland cement which was suitable for all applications when no performance specifications, such as low sulphate exposure, was required.

b. Water

Water was one of the key elements in the concrete mix. It was important to accelerate the chemical reaction, called hydration reaction, which became a paste together with cement and formed a chemical bond with cement components. The normal concrete required a compressive strength between 20 MPa and 45 MPa. To obtain a normal concrete strength between 20MPa to 40MPa, the water-cement ratio was in the range from 0.40 to 0.45 according to BS EN 1008: 2002 [7].

c. Aggregates

Aggregates occupied the largest number of constituents in concrete, and they were the important factor contributing to the strength of concrete. According to BS 882: 1992, the aggregates passed through sieve No.4 (4.75 mm) openings were referred to as fine aggregates while the rest retained above No.4 sieve were considered as coarse aggregates. The maximum size of crushed coarse aggregates used were 10mm while the minimum fine aggregates size was 0.075mm [3].

d. Spent garnet

The spent garnets were obtained from the Malaysia Marine and Heavy Engineering Holdings Berhad (MMHE) at Pasir Gudang, Johor. They were ensured as fine aggregates, which were sieved through 5mm sieve prior to conducting the related laboratory work.

2.2 Mix Proportions

In this study, specimens of concrete of Grade 30 were proposed. The specifications and mix concrete design were determined based on the DOE method. The ratio of the concrete constituents including cement, water, fine aggregates and coarse aggregates was proposed as 1: 0.45: 1.27: 1.92. The spent garnet as partial sand replacement was used in percentage by weight of sand in 0%, 10%, 20%, 30% and 40% respectively. The specimens were represented as G0, G10, G20, G30 and G40. According to the mixing ratio, the mix proportions of concrete content shown in Table 1.

Table 1: Mix proportions of concrete contents

Mixes	Mix proportions of concrete content (kg/m^3)				
	Cement	Water	Sand	Spent Garnet	Coarse Aggregate
G0	510	230	650	0	980
G10	510	230	585	65	980
G20	510	230	520	130	980
G30	510	230	455	195	980
G40	510	230	390	260	980

2.3 Laboratory Tests

a. Sieve analysis (BS 812-103.1:1985) [8]

The particle size distribution of fine aggregates was determined via sieve analysis. The apparatus needed in this test were a set of sieves and a balance. The sieve sizes were 10mm, 5mm, 2.36mm, 1.18mm, 600μm, 300μm, 150μm and 75μm. Sand and spent garnet were dried at a temperature of 110 ± 5 °C and weighted of 0.5kg. The sieves were arranged according to size and placed on a mechanical shaker. The specimens were poured into a sieve and shaken for 5 minutes. The aggregate retained on each sieve plate were weighted and recorded. The fineness modulus was evaluated by the formula in equation 1:

$$Fineness\ Modulus = \frac{Sum\ of\ cumulative\ percentage\ retained}{100\%} \qquad Eq.\ 1$$

b. Slump test (BS EN 12350-2:2019) [9]

Slump test was conducted to determine the workability and consistency of freshly mixed concrete. First, the slump cone was placed on a solid, impermeable horizontal base plate. The fresh concrete mix was then filled in three equal layers in cone and each layer was tamped 25 strokes using rounded end of tamping rod 600mm long with 16mm diameter. The top layer was finished flush with the cone's apex. The cone was cautiously and gently raised, allowing the concrete to settle, and the slump was instantly determined by estimating the difference in height between the mould and the highest point of the specimen by using measuring tape.

c. Compressive strength test (BS EN 12390-3:2019) [10]

Concrete specimens were proposed in 100 x 100 x 100 mm^3. Concrete mix was filled in the moulds by a few equal layers (each approximately 50mm thick) with 35 strokes (every area of 10mm^2) for compaction. They were removed from moulds and cured within 24 hours. Compressive strength tests were conducted at the concrete age of 7 and 28 days respectively. The specimens were tested using Compressive Testing Machine (CTM) by applying load gradually until they broke down and no longer withstand the strength. The strength for each specimen was tabulated then.

d. Flexural strength test (BS EN 12390-5:2019) [11]

Flexural strength was the capacity of an unreinforced concrete beam or slab to resist bending due to applied stress. The size of the specimens was 100 x 100 x 500 mm^3. Concrete mix was filled in the moulds by a few equal layers (each approximately 50mm thick) with 35 strokes (every area of $10mm^2$) for compaction. They were removed from moulds and cured within 24 hours.

The beam specimens at the age of 28 days were removed from the curing tank and tested under a three-point loading test machine. Beam specimens were aligned with the test machine, with the loading and roller support in even contact with the specimens. The load was applied constantly at a consistent pace with no shock until maximum load made the beam fractured. The flexural strength of concrete was determined by the formula in equation 2:

$$\sigma = \frac{3FL}{2bd^2} \quad \textit{Eq. 2}$$

where
σ = flexural strength, (MPa or N/mm^2);
F = maximum load at the fracture point (N) ;
L = length of the support span (mm);
b = width of concrete (mm);
d = thickness of concrete(mm).

3. Results and Discussion

3.1 Sieve Analysis Result

The fineness modulus for sand and spent garnet were found to be 3.18 and 2.14 as shown in Table 2 and 3 respectively. Sand has much greater fineness modulus value about 33% than spent garnet. Sand was in the category of coarse sand with fineness modulus between the range of 2.9 to 3.2 [12]. Spent garnet has much smaller fineness modulus than the minimum requirement of 2.3 as marked in ASTM C33 standard [13].

Table 2: Sieve analysis of sand

Dry weigh of material:	0.5kg		Sand	
Sieve Size	Mass of retained (kg)	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative percentage passing (%)
10mm	0	0	0	100
5mm	0	0	0	100
2.36mm	0.013	2.6	2.6	97.4
1.18mm	0.035	7	9.6	90.4
600µm	0.17	34	43.6	56.4
300µm	0.151	30.2	73.8	26.2
150µm	0.088	17.6	91.4	8.6
75µm	0.029	5.8	97.2	2.8
Pan	0.014	2.8	-	0
Total	0.5	100	318.2	-
Fineness modulus (FM) of fine sand = 3.18				

Table 3: Sieve analysis of spent garnet

Dry weigh of material:	0.5kg		Spent Garnet	
Sieve Size	Mass of retained (kg)	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative percentage passing (%)

10mm	0	0	0	100
5mm	0	0	0	100
2.36mm	0	0	0	100
1.18mm	0.0.1	2	2	98
600µm	0.032	6.4	8.4	91.6
300µm	0.113	22.6	31	69
150µm	0.224	44.8	75.8	24.2
75µm	0.105	21	96.8	3.2
Pan	0.016	3.2	-	0
Total	0.5	100	214	-
Fineness modulus (FM) of spent garnet = 2.14				

This may influence the behaviour of concrete in terms of workability and strength as well when spent garnet is used as the sand replacement. However, the percentage of particles retained on 5mm sieve size were 0% for both sand and spent garnet, which lie between the recommended ranges of 0 to 5% of fine aggregates grading requirement of BS 882 [14].

The Figure 1 illustrated the grading outcomes of both spent garnet and sand based on sieve analysis tests. According to the pattern of both curve shape for sand and spent garnet, it showed a well-graded pattern where they opposed various sizes of particles and were beneficial in filling the voids between the larger particles of other materials. Moreover, the grading coefficient for sand was 1.09 while for spent garnet was 1.07 as shown in Table 2. Sand and spent garnet have the grading coefficient greater than 1.0 which were considered as well graded theoretically [5]. Thus, it can be confirmed that the particle grading of spent garnet corresponded to the required grading of fine aggregates to produce concrete.

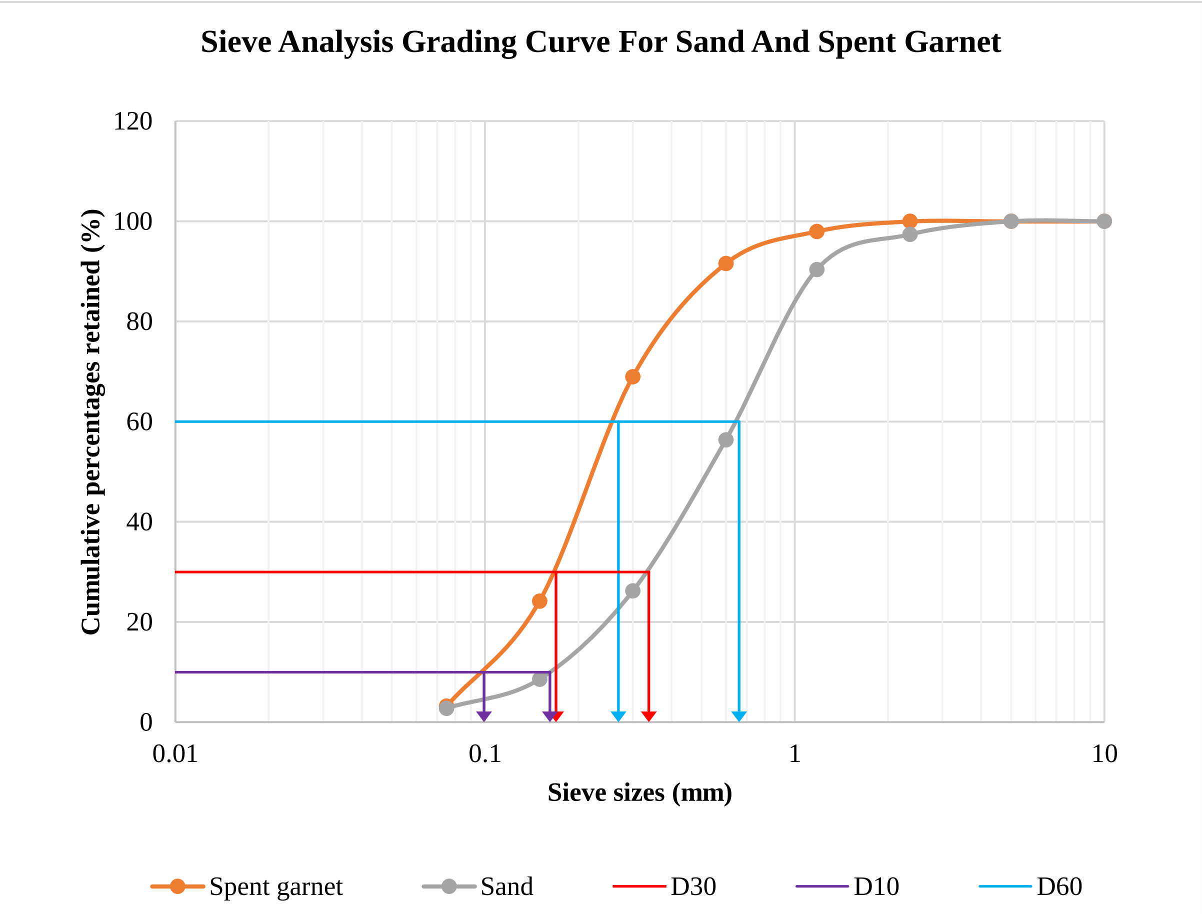

Figure 1: Sieve analysis grading curve for sand and spent garnet

Table 4: Grading coefficients of spent garner and sand

Material	D10	D30	D60	Grading Coefficient, $(\frac{D30^2}{D60\ x\ D10})$
Sand	0.16	0.34	0.66	1.09
Spent garnet	0.10	0.17	0.27	1.07

3.2 Slump Test Results

The results of slump of each fresh concrete were tabulated in Table 5. The control specimen has the slump of 35mm which is in the range of design slump about 30mm to 60mm. The fresh concrete contained of spent garnet produced a higher slump as the percentage replaced increased. The slumps were raised from 50mm to 85mm. The higher percentage of spent garnet in concrete generated higher slump due to its high density and low ability to retain its consistency [15]. This was also influenced by the differences between river sand and spent garnet in particle size distribution, shape and surface morphology [2].

Table 5: Slump of specimens with different % of spent garnet

Specimen	% Replacement of Spent Garnet	Slump (mm)
G0	0	35
G10	10	50
G20	20	72
G30	30	78
G40	40	85

3.3 Compressive Strength Results

The compressive strength of concrete specimens at 7 and 28 days were tabulated in Table 6. It claimed that concrete should gain about 70% of the target strength at the age of 7 days [16]. In this study, the target strength was set at 30MPa, so the required strength at the age of 7 days was supposed to be 20MPa and above. Control specimen gained 26.3MPa at the 7 days of curing. The 10% of spent garnet replaced produced 20.8MPa and increased to 24.3MPa with 20% of spent garnet used. However, it reduced gradually to 16.0MPa and 15.3MPa in 30% and 40% of spent garnet used respectively. At the age of 28 days, the control specimen developed a strength of 35.6MPa. The specimen G10 produced strength of 29.8MPa and increased to 34.6MPa by specimen G20. The specimens G30 and G40 gained the compressive strength of 24.3MPa and 22.3MPa respectively.

In overall, specimens with the presence of spent garnet have lower compressive strengths than that of control specimens. Among the percentages, using 10% and 20% of spent garnet showed a desired compressive strength which hit the target strength in 7 and 28 days of minimum 20MPa and 30MPa respectively. However, sand replacement by 30% and 40% showed significantly weak compressive strengths on 7 and 28 days.

Table 6: The compressive strength of specimens at the age of 7 and 28 days

Specimen	Compressive Strength (MPa)	
	7 Days	28 Days
G0	26.3	35.6
G10	20.8	29.8
G20	24.3	34.6
G30	16.0	24.3
G40	15.3	22.3

In Figure 2, it demonstrated the strength increment of the various concrete specimens from the curing period of 7 days to 28 days graphically. In the overall perspective, the concretes containing spent garnet as partial sand replacement have weaker compressive strength than the normal concrete over the period of curing. The overall reduction in compressive strength was affected by the smaller fineness of spent garnet particles compared with sand. This consequently caused a lesser appropriate gradient and shape of spent garnet particles to fill in the pore spaces in the mixed concrete. Thus, reduction of strength due to the smaller particle sizes overall.[2].

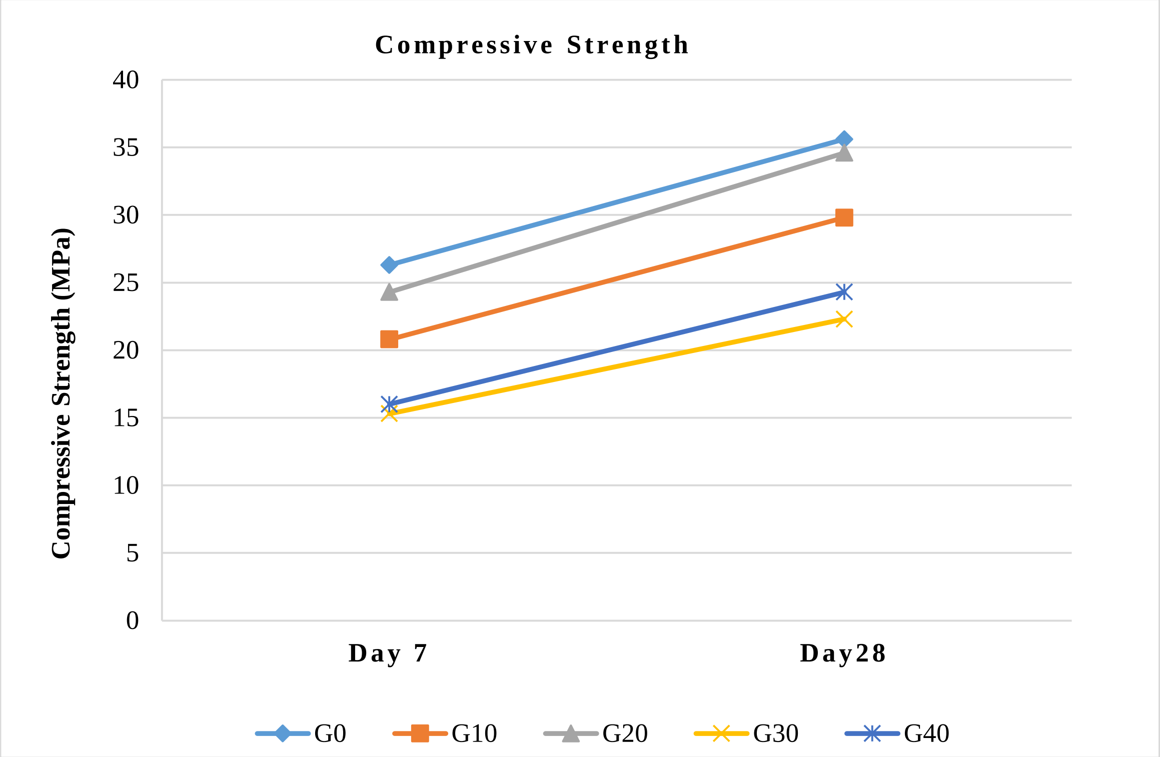

Figure 2: Strength development in day 7th and 28th

It was observed when 10% of spent garnet was used, the compressive strength was lower compared with plain concrete. It showed a rising strength development until the increment of replacement up to 20% spent garnet was used. This was due to the appropriate amount of spent garnet particles to fill in more void pores in concrete and tend to decrease the porosity, thereby increasing the compressive strength. However, it declined significantly when using 30% and 40% of spent garnet as sand replacement. This was explained that the excessive spent garnet would produce weaker bonding strength in the between the concrete and cement paste, thus, strength declined gradually [15].

The concrete with 20% of spent garnet showed the maximum compressive strength. It gained the nearest strength to the plain concrete with the discrepancies about 7% and 3% on day 7th and 28th respectively. This is possible that replacement of 20% spent garnet could produce a comparable strength to a normal concrete. The minimum strength was developed using 40% of spent garnet. It was about 42% and 26% of strength less than the plain concrete on 7 and 28 days, respectively.

3.4 Flexural Strength Results

The flexural strength of concrete was calculated using Eq.2. The findings of the flexural strength of concrete specimens at age 28 days were summarised in Table 7. The control specimen produced the flexural strength of 13.11MPa. Nonetheless, it showed a lower value of flexural strength by all of the concrete with partial spent garnet. This was because of the presence of spent garnet, it produced weaker bonds with the cement. Moreover, the low sand ratio caused the weak bonding to the fine aggregate and the plaster too [2]. Thus, the concrete with spent garnet has the weaker ability to resist the bending in overall.

Table 7: Maximum load applied and the corresponding flexural strengths

Specimen	Max Load Applied. *F* (kN)	Flexural Strength (MPa)
G0	17.48	13.11
G10	17.30	12.96
G20	17.38	13.04
G30	16.34	12.26
G40	15.84	11.88

Based on Figure 3, the flexural strength has increased when the usage of spent garnet up to 20%. This situation was attributed to the increases of fine aggregate which decrease the porosity by filling in more voids between the aggregates. Thus, increasing the ability strength to withstand the bending stress. The gradual reduction of flexural strength by using 30% and 40% of spent garnet contributed to 12.26MPa and 11.88MPa respectively. This reduction was affected by the excessive amount of spent garnet in reducing the sand ratio significantly and therefore, decreasing the interlocking between fine aggregate and binders [17]. It was concluded that with 20% of spent garnet used, it has the nearest flexural strength to the control which is 0.5% in difference.

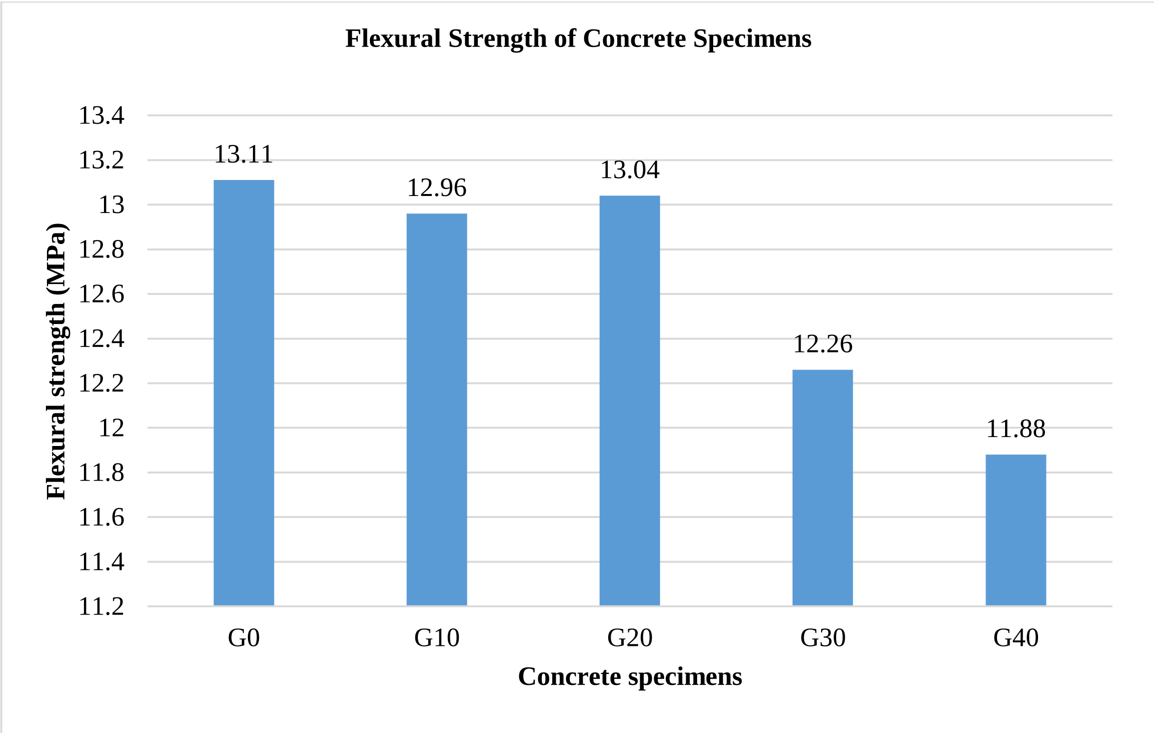

Figure 3: Flexural strength of concrete specimens

4. Conclusion

In overall, the sieve analysis showed that the spent garnet has smaller fineness modulus than sand, but both were found as well-graded particles. For the workability, it was enhanced by the incremental amount of spent garnet in fresh concrete. However, the compressive and flexural strengths of concrete consisting of spent garnet were discerned to be lower compared to the control sample at all stages of replacement. Nonetheless, it is established that the spent garnet is a prospective candidate for sand replacement up to 20% which gave the optimum performance among the others.

It is concluded that spent garnet has the potential as a promising resource for improving the green concrete technology and reducing the environmental issues. It is suggested to study the behaviour of concrete consisting of spent garnet as sand replacement from more aspects such as subject to chemical reaction and thermal effects for further study.

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