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Performance of Spent Garnet as Sand Replacement in Concrete at High Temperature

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Abstract: Garnet is ideal for many commercial uses due to its potential to be recycled. The dumping millions of tons of spent garnet in landfills, quarries, oceans and waterways will cause the creating environmental concerns. In this study, spent garnet as a sand replacement is produced to innovate sustainable concrete. The research objectives are to study the effects of strength of spent garnet as sand replacement in concrete mix at high temperature and to evaluate its physical properties of spent garnet. Several laboratory experiments were conducted to determine the physical and its compressive strength before and after exposed to high temperature. Furthermore, the test for the physical properties that had been conducted were, specific gravity, bulk density and water absorption test. Other than that, the compressive strength of 30MPa at 28 days for trial mix design were prepared accordingly. The cube specimens of 100 × 100 × 100 mm were provided with substitution of 0%, 10%, 20%, 30% and 40% of spent garnet as sand replacement with 0.45 of water cement ration. All the concrete mixes containing spent garnet were produced slump of 30-60mm. Based on the test result, the cube specimen of 40 percent of spent garnet after heated started decrease in term of strength due to the present of the excessive of spent garnet particles in the concrete which can weaken the bond between aggregates and the cement paste. Thus, it reduces the concrete strength in term of less compaction of concrete has lower bonding strength.

Keywords: Garnet, Spent Garnet, Physical Properties and Compressive Strength.

1. Introduction

Malaysia is a growing market that is experiencing fast economic development. As a result, the construction industry plays a significant role in economic management and operations, both in the private and public sectors. To research the construction industry's growth in Malaysia, a comprehensive examination developed in order to plan and prepare in advance to tackle the building industry's

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difficulties during the crisis. As Malaysia's construction industry is a significant economic field, a thorough study should identify its growth trends. It is expected that this study will apply to the construction industry's planning and investment sectors in the future, taking into consideration any changes in size or request that may occur. A detailed examination of the pattern of industrial expansion should be conducted in this regard.

The sand extraction is the removal of sand; it is the natural form. Sand is used for all forms of projects, such as land reclamation, artificial island-building, and coastlines' stabilisation. Such projects have economic advantages, but there are also environmental issues with sand mining. When the extraction yield of sand, gravel, and other materials surpasses the natural processes' resources, ecological concerns occur. Numerous articles have been written about these impacts, and the next step is to figure out what to do to minimize, eliminate, or avoid these environmental effects, which is referred to as vulnerability reduction. The Malaysian economy relies heavily on sand mining. It should be acknowledged that the processes of searching, extracting, concentrating, refining, and shipping minerals have a high potential for causing environmental disruption. Furthermore, sand mining has a negative influence on water quality and the stability of the stream bed and banks. Mining can also alter sediment supply and channel shape, deepening the channel and causing habitat sedimentation downstream.

In concrete, a large amount of wasted garnet is utilised as fine aggregates. Consequently, it has a significant impact on the performance of concrete at high temperatures. Therefore, it was supposed to deliver better performance as fine aggregates in concrete at elevated temperatures than river sand. Besides that, concrete is one of the materials that sustain a fire source. However, at higher temperatures, mechanical and physical properties such as weight, aggregate-cement binding, connection with steel reinforcement, and chemical resistance change in reinforced concrete [3]. Typically, when temperature reached 350°C, the aggregates remain stable. When aggregates are exposed to high temperatures, they experience changes in thermal expansion, conductivity, and chemical stability [7]. Furthermore, when subjected to high temperatures, concrete undergoes a colour change; the type of particles used in the concrete determines this phase. From the report that concrete containing silicate, the aggregates undergoes to red or brownish when heated up to 300^{O}C-600^{O}; when the temperature heated in between 600^{O}C-900^{O}C, the aggregates turns to a whitish-grey colour and after that when it heated to the range of 900^{O}C-1000^{O}C changes it into a beige colour [2].

The previous research has proven that when subjected to high temperatures, The various types of aggregates used affect the properties of the concrete. The influence of aggregates on the physical and mechanical characteristics of normal concrete (NC) when exposed to a high temperature of 200°C, the compressive strength of concrete including basalt, riverbed gravel, and dolomite reduced by 5 to 20% [2]. It was discovered that aggregates of siliceous and carbonate in normal concrete exhibit similar pattern in the stress-strain curve when heated to 400^{O}C [4]. However, Nor et al, [5] state that, 40% of spent garnet in concrete gives the lowest compressive strength test result, this is due to the excessive present of spent garnet in concrete which can weaken the aggregates and the cement paste [5]. Thus, as the concrete becomes less dense, the bonding strength decreases, reducing the concrete strength. These investigations were utilized waste garnet in the concrete mix. Further, the strength of the concrete containing waste garnet tested before and after heated.

From the previous study, extensive research on the chemical and physical properties of spent garnet and their effects on the strength and bonding of concrete has been studied. However, another researcher has not thoroughly investigated the study for concrete containing wasted garnet. Generally, the behaviour of concrete containing spent garnet when exposed to elevated temperature since aggregates form a large proportion of concrete volume, around 70 per cent, and are likely to affect the impact of concrete when exposed to fire [6]. This rise in the use of spent garnet would mitigate environmental issues and have sustainable, eco-friendly concrete. Therefore, spent garnet poses a danger to ecological balance and diversity. Garnets can be reused nearly three to five times while retaining intact their total properties [1]. Besides, for abrasive blast purpose, these recycled garnets decay at a degree beyond which they are non-reusable. The spent garnet may have advantages in sustainable development than Portland cement upon its usage as a partial precursor substance.

2. Materials

For material preparation, there are a lot of requirements and related rules mentioned in British Standard. Before beginning the testing, the amounts of cement, water, coarse, and fine aggregate (spent garnet) are estimated using the DOE technique. Then, there are two tests for fresh and hardened concrete containing spent garnet. Slump test were conducted to examine the slump height of fresh concrete, while compressive strength was tested for hardened concrete. Other than that, the physical properties of spent garnet were also investigated through specific gravity, bulk density and water absorption test. For this study, the data collection is taken from the Faculty of Engineering Civil Engineering & Built Environment.

2.1 Materials

The principal concrete ingredient in this investigation was ordinary Portland Cement (OPC). According to BS EN 933 (2012), for coarse aggregates, the fraction that passes 10 mm and is retained at 5 mm was utilised. The spent garnet that used are the portion passing 2.36mm, respectively with 3606 kg/m³ density of spent garnet. Five batches of concrete mix consisting of 0 percent, 10 percent, 20 percent, 30 percent and 40 percent of spent garnet were prepared. For compressive strength test, concrete specimens with dimensions of 100 mm × 100 mm × 100mm were prepared and exposed to high temperature at 300°C in 4 hours before conducted the compressive strength test.

2.2 Methods

The water-cement ratio was determined by trial and error to be 0.45 in order to produce a workability of 30-60 mm after 28 days and a concrete strength of 30 MPa. Mix proportion of cement, fine aggregates and coarse aggregates are shown in the Table 1. Furthermore, the mix constituent required for the production of 1 metre³ grade C30 concrete are tabulated in Table 2.

Table 1: Ratio for C30 concrete

Characteristics compressive strength at 28 days	30 N/mm²
Ratio: water, Fine Aggregates, Coarse Aggregates	0.45: 1.34: 2.49

Table 2: Mix Proportion of Concrete Design

Type of mixers	Mix Proportions (kg/m³)				
	cement	water	sand	spent garnet	coarse aggregates
C0	456	205	612.0	-	1137
C10	456	205	550.8	61.2	1137
C20	456	205	489.6	122.4	1137
C30	456	205	428.4	183.6	1137
C40	456	205	367.2	244.8	1137

For sieve analysis, the apparatus needed in these tests are a set of balance and sieves. The size of sieve stacked for coarse and fine aggregates are shown in Table 3. The mechanical sieve shaker was used in this test to create vibration of the sieve in order to cause the particles to bounce for 5 minutes. The aggregates retained in the sieve was weighted and being record. Percentage retained in each sieve were calculated and the cumulative percentage were determined. Fine modulus can be evaluated by the following formula from equation 1:

$$Fine\ modulus = \frac{sum\ of\ cumulative\ precentage\ retained}{100\%} \qquad Eq.\ 1$$

Table 3: Size of sieve stack of fine and coarse aggregates

Coarse aggregate (mm)	Fine aggregates (mm)
25.00	5.00
20.00	2.36
14.00	1.18
10.00	600 μm
5.00	300 μm
3.35	150 μm
2.36	163 μm
Pan	pan

Specific gravity, bulk density, and water absorption tests were used to characterise wasted garnet. The standard test for Specific gravity of fine aggregates is IS:2386 (part 3); 1963 and the formula was shown is the Eq. 2. ASTM C 29 (AASHTO T 19) specifies a standard test technique for measuring the bulk density of sand and following formula from Eq. 3. The water-cured concrete cubes (28 days) were then dried in the oven at 50 ±2°C for 3 days until the bulk remained consistent before being weighed again. This weight was recorded as the concrete cube's dry weight (W1). Samples were tested in contact with water from one surface, with the water level no greater than 5 mm above the base of the sample. Water flow from the peripheral surface is stopped by appropriately sealing it with non-absorbent coating for a predetermined time interval in accordance with [ASTM C 1585] with their arrangement as shown in Eq. 4. This weight is then recorded as the wet weight (W2) of the concrete cube.

$$Specific\ gravity\ of\ spent\ garnet = \frac{(W2 - W1)}{(W2 - W1) - (W3 - W4)} \qquad Eq. 2$$

W1= Weight of pycnometer in air (W_1 g)
W2 = Weight of pycnometer+ Fine aggregate (W_2 g)
W3= Weight of pycnometer + water + Fine aggregate (W_3 g)
W4= Weight of pycnometer+ water in air (W_4 g)

$$Compacted\ unit\ weight\ of\ bulk\ density = \frac{w}{v} \qquad Eq. 3$$

W = Weight of compacted aggregate in cylindrical metal measure, kg
V = Volume of cylindrical metal measure, litre

$$water\ absoprtion\ = \frac{W2 - W1}{W1}\ x\ 100 \qquad Eq. 4$$

The test was separated into two conditions: fresh and hardened concrete characteristics. For fresh properties, slump test according to BS EN 12350-2 were conducted to examine the workability of concrete mix. For hardened concrete, compressive strength test according to BS EN 12390-3 were conducted. Prior to the compressive strength tests, the concrete specimens of spent garnet were subjected to a high temperature of 300°C for 4 hours. The electrical furnace could be programmed to follow the ISO 834 standard temperature-time curve and represented by the following Eq. 5.

$$T\ = 345log10\ (8t + 1) +\ T^0 \qquad Eq.\ 5$$

3. Results and Discussion

3.1 Physical Properties of Spent Garnet

The result based on the physical properties of spent garnet and sand are shown in Table 4.1. From the table, it can be seen that spent garnet has a higher bulk density than sand which is the value of spent garnet and sand 1922kg/m^3 and 1640kg/m^3 respectively. Furthermore, when compared to sand, spent garnet has a larger bulk density, more fine particles, and less void content. Thus, it has least amount of air space between particles because of the particles are closely packed to each other which then contributed to higher density. The water absorption of wasted garnet is 6 percent higher than that of sand, which is likely owing to the presence of extra moisture on the surface particles. The excessive amount of water will increase the workability but produce effect for the strength of the concrete. The specific gravity of spent garnet and sand were 3.0 and 2.6 respectively. The high specific gravity of the spent garnet is due the existence of iron oxide (Fe_2O_3) in it. The previous study H.L Mutasshar, 2018 was also agreed with the result of this study.

Table 4: Physical Properties of Spent Garnet

Properties	Spent Garnet	Sand	Permissible limits
Specific Gravity	3.0	2.6	2.6-2.7
Bulk Density	1922kg/m^3	1640kg/m^3	1300-1750
Water absorption	6%	3%	2%-3%

3.2 Compressive strength test

3.2.1 Heating regime

The use of spent garnet as a sand replacement is expected to perform better than normal concrete at elevated temperature. It could also provide a significant advantage to standard concrete at elevated temperature. When the temperature rises to 400°C, the oxidation of iron contained in spent garnet causes the colour of the concrete to shift from typical grey to brownish. The major problem for standard concrete was the spalling effect when the temperature rises above 400^{O}C. Besides that, the concrete specimen of 20 percent of spent garnet or higher were fully changed from normal grey to brownish but the specimen without spent garnet and 10 percent of spent garnet were maintain in normal grey state.

3.2.2 Strength test

The compressive strength result for the concrete specimen of spent garnet at 28 days are shown in Table 5. Based on the result, it can be concluded that the concrete specimen containing spent garnet after heated has higher value of strength than specimen concrete of spent garnet before heated. In addition it can be seen that cube specimens of with 30 percent of spent garnet shows the best comparable strength when compare to conventional concrete. This might be owing to the filling action of wasted garnet particles, which fill in voids or pores in concrete mixture, resulting in thick cement with increased strength. The previous research by Nor Hasanah Abdul Shukor, 2020 was also agreed with the result of this study.

Table 5: The Compressive strength of the Specimen before and after heated

Specimens	Compressive Strength before heated – 28 days (MPa)	Compressive Strength after heated – 28 days (Mpa)
C0	35.6	35.1
C10	29.8	39.7
C20	34.6	41.2
C30	24.3	45.5
C40	22.3	42.4

Furthermore, after heating, the specimen containing 40 percent wasted garnet began to lose strength due to the presence of too many spent garnet particles in the concrete, which can impair the connection between the aggregates and the cement paste. Thus, the concrete become less dense has lower bonding strength and therefore it reduces the concrete strength. This finding agreed well as the previous study by Nor Hassanah Abdul Shukor Lim, 2020. Further observation can be made from Figure 1, It can be seen that cube specimens of wasted garnet that have been subjected to high temperatures have more strength than cube specimens that have been exposed to normal temperature.

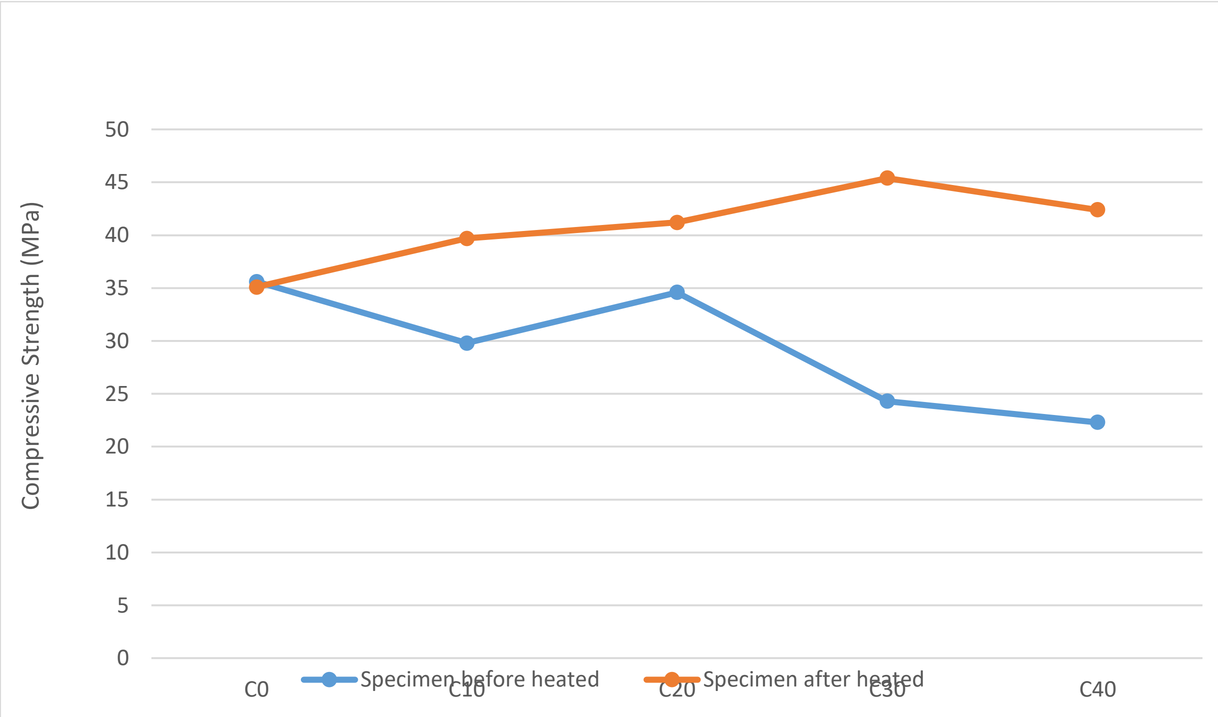

Figure 1: The difference of compressive strength before and after heating after 28 days

4. Conclusion

Overall the physical properties of spent garnet and the compressive strength after exposed to high temperature at 300°C for 4 hours can be presented comprehensively through this study. Specific gravity, bulk density, and water absorption tests were used to characterise wasted garnet. Furthermore, the compressive strength of cube specimen was test also obtained after exposed to high temperature.

The characterization of spent garnet using specific gravity, bulk density and water absorption test were record accordingly.

The compressive strength test results after and before heating were recorded in table form and graphed to examine the difference in strength between two conditions of cube specimen of spent garnet. After heating, the specimen with 40 percent wasted garnet began to lose strength due to the presence of too many spent garnet particles in the concrete, which can impair the connection between the aggregates and the cement paste. As a result, the less compaction of the concrete has reduced bonding strength, affecting concrete strength. When compared to normal concrete, the cube specimens containing 30% spent garnet had the highest equivalent strength. This might be owing to the filling action of wasted garnet particles, which fill in voids or pores in mortar mixtures, resulting in thick mortar with increased strength. However, further study must be carried out extensively obtain more comprehensive results of concrete containing spent garnet.

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