

Energy Absorption Study of Concrete Incorporating Spent Garnet Subjected to Low-Velocity Impact Loads

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Abstract

Several researchers examine the concept of mitigating the impact during collisions between vehicles and concrete barriers, such as enhancing the energy absorption capacity of the barriers. As a result of this matter, this issue demands the use of sand, potentially resulting in the exploitation of natural resources. Hence, this study was utilizing waste material such as spent garnet (SG) as a partial fine aggregate replacement under low-velocity impact loads in order to predict the energy absorption produced from concrete containing SG. SG was used as a partial fine aggregate replacement using 0%, 10%, 20% and 30% of SG percentage. This study experimentally examines the compressive strength of sample which yielded at 43.5 MPa, 41.3 MPa, 42.1 MPa and 40.7 MPa for SG0, SG20, SG30 and SG40 respectively. The optimum percentage was chosen, and the block specimens were prepared for low-velocity impact test. All 12 block specimens were tested under a low-velocity impact test with fix velocity at 2.43 m/s. The results reveal that SG20 indicates ideal crater since the crater diameter almost same as diameter for nose hemispherical projectile used in this study which is 40 mm. The penetration depth for block specimens are 1.74 mm, 1.79 mm, 1.76 mm and 1.84 mm for SG0, SG20, SG30 and SG40 respectively. Thus, the results in penetration depth shows by the increment of SG content in the concrete mix produce higher penetration depth. In term of energy absorption, the result was directly proportional to penetration depth which the higher penetration depth produces higher energy absorption. Thus, the 20% SG mixture demonstrated the most promising result between compressive strength and energy absorption. This indicates that incorporating 20% SG into concrete barriers has significant potential for improving their performance, making them more effective in mitigating the impact of vehicle collisions and reducing the risk of fatalities.

1. Introduction

Concrete, one of the oldest and most widely used structural materials, is indispensable in the construction industry, where it serves in buildings, infrastructure, and defence structures such as road barriers, retaining walls, and military bunkers [1][2]. The rapid growth of the construction field has driven a high demand for fine aggregates like sand, leading to resource depletion and excessive sand mining activities. The industry consumes

approximately 9 billion tonnes of sand and gravel, 1.5 billion tonnes of cement, and 1 billion tonnes of water annually [3]. While concrete is designed to endure impact loading from explosions or collisions, conventional concrete barriers have limited energy absorption capabilities, posing significant risks to road users during accidents. Such barriers often cause rebounds and severe vehicle damage, highlighting the need for improved materials [4][5]. To address environmental concerns and enhance safety, green concrete has emerged as an eco-friendly alternative, incorporating waste or recycled materials to promote sustainability. One such material is “spent garnet,” a byproduct of garnet used in industrial applications like abrasive blasting and water filtration. With global garnet production estimated at 440,000 tonnes, significant amounts are discarded in landfills and water bodies, causing environmental pollution [6]. By integrating spent garnet into green concrete, the construction industry can mitigate waste issues and improve the performance of road barriers. Regarding this issue, it is important to reduce the pressure on the environment. In this study, the use of SG from waste materials as a fine aggregate partial replacement for concrete barriers has been selected as the solution to increase the energy absorption toward concrete road barriers in order to reduce the fatality of vehicle accidents. The reason for choosing SG in this study is that it can reduce the amount of SG thrown in the landfill area as waste material. In addition, concrete incorporating SG is created to improve the performance of conventional concrete especially in terms of energy absorption when it is subjected to impact loading. Thus, this study will experimentally examine the efficiency of the proposed concrete incorporating SG under low-velocity impact loads.

SG is a byproduct generated from the garnet abrasive blasting process, is notable for its distinct physical and chemical characteristics. These properties make SG an attractive and viable material for partially replacing fine aggregates in various construction applications. Its composition and attributes contribute to its potential as a sustainable alternative to natural sand. One of the most visually distinctive features of SG is its reddish-pink appearance, which arises due to its high concentration of iron oxide (Fe_2O_3), distinguishes it from natural sand [7][8]. Its specific gravity ranges from 3.0 to 4.16, significantly higher than natural sand, further reflecting its iron oxide content [9][10][11]. During its industrial application, SG particles undergo substantial mechanical wear and tear, including fracturing and abrasion which resulting in finer particles. SG particles undergo fracturing and abrasion during industrial use, resulting in finer particles. The pH value of SG is 8.3 and above 7, indicating an alkaline nature, while its melting point is 1250 °C, and its hardness on the Mohs scale is 7.5 [11][12][13]. SG has a water absorption value ranging from 5.8% to 11.4% [9] – [15]. The bulk density of SG between 1922 and 2300 kg/m^3 [9][11][14]. Additionally, its fineness modulus, ranging from 1.74 to 2.05, indicates finer materials, which can influence the properties of concrete mixes.

Energy absorption refers to the process by which a material or system takes in and dissipates energy when exposed to an external force or impact. The energy absorption mechanism of materials is affected by the sudden force generated by external force or impact [2]. The phenomenon of energy absorption is intricately linked to the force released by the impactor as it strikes the surface of the target. In other words, the ability of a material or system to absorb energy highly depends on the magnitude and nature of the force applied by the impacting object upon a contact. By applying the principle of energy conservation, energy absorption can be comprehended as the response of the target to the forces released by the impactor which arise from its mass and acceleration [2]. According to Hadipramana et al. [2], the presence of RHA contributed to increased strain of FC porosity. It delayed the collapse of porosity and made the FC denser. Thus, this factor can affect the material energy absorption in the sample. Equation (1) was used to determine the energy absorption of both materials when subjected to impact load. The finding showed that the energy absorption of both materials was not significant even though the FC with RHA already increased the strength of the sample. Additionally, the higher the velocity impact, the higher the value of energy absorption. According to Kadir et al. [16], the empirical formula for the energy absorption as shown in equation (1), the relationship between the penetration depth is directly proportional to the energy absorption. Hence, the energy absorption will increase if the penetration depth is increased. The study obtained that the higher the percentage of Crumb Rubber (CR), the higher the energy absorption acquired from the impact test. The energy absorption follows the law of energy conservation, which states that the energy cannot be destroyed but can be transferred to others. The energy absorption is also influenced by the mass of the impactor in the impact test. In order to calculate the energy absorption of concrete using the empirical formula, the values required are the mass of the impactor, acceleration due to gravity and penetration depth.

$$E = m \cdot g \cdot X \quad (1)$$

- E = Energy absorption (Nm)
- m = Mass of impactor (kg)
- g = Acceleration due to earth's gravity (9.81 m/s^2)
- X = Penetration depth (m)

2. Materials and Methodology

2.1 Materials

The results for particle size distribution of sand and SG derived from sieve analysis are presented in Figure 1. The particle size distribution of sand and SG obtained from sieve analysis falls between the lower and upper limit of fine aggregate grading limit as specified in BS 882:1992 [17]. Thus, SG can be classified as fine aggregate and relevant as a partial replacement for sand in this study for concrete mix. The value of the fineness modulus of sand was 2.73, whereas the SG had a fineness modulus value of 1.40. The sieve analysis was carried out by referring BS 882:1992[17].

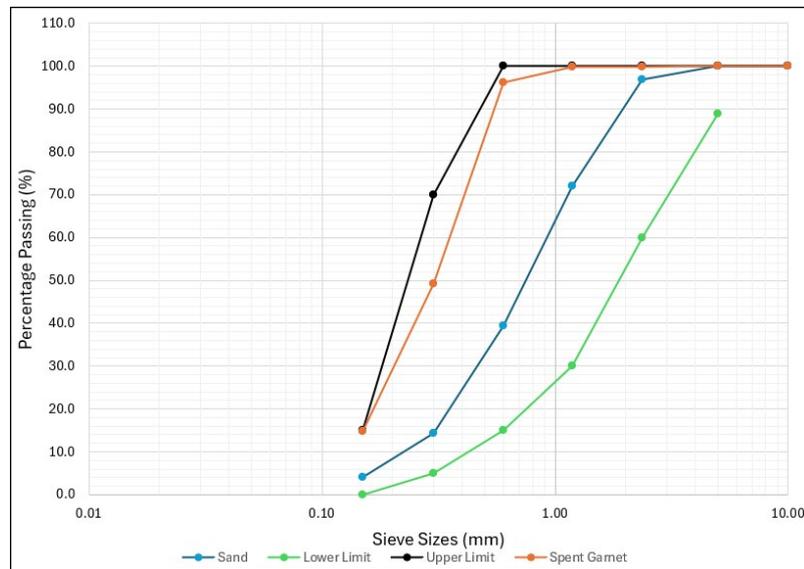


Fig. 1 Particle size distribution of sand and SG

2.2 Sample Preparation

In this study, there are two variations of samples which are cube and block samples. A total of 36 specimens have been provided, including 24 cube specimens for the compressive strength test to identify whether the concrete has achieved the required strength by following BS 12390-3:2002 [18] and 12 block specimens for the low-velocity impact test to determine the crater and penetration depth by following a similar method in BS EN 22248:1993 [19]. After the concrete was demoulded 24 hours after curing, all specimens underwent a curing period of 7 and 28 days for the compressive strength of the cubes and 28 days for the low-velocity impact test of the blocks in a water tank.

2.3 Low-velocity Impact Test

All the concrete blocks were tested under the low-velocity impact test by using the hemispherical nose projectile with a diameter of 40 mm as an impactor on the concrete block surface. The drop weight impactor used is about 100 kg following the previous study [20] and the drop height is about 0.3 m with a constant velocity of 2.43 m/s. This height was determined based on the sample size due to the sample was slightly reduced from the previous study [21]. Moreover, the height of the impactor is already enough to create penetration depth and cratering diameter upon the impact on the concrete block surface. For safety purposes, the lower portion of the concrete block specimens was securely fixed with wood in order to prevent any movement of the concrete block during a collision with the projectile. Figure 2 (a) and (b) show the concrete block dimension and the impact rigs used in this study.

This test was significant in order to investigate the behaviour of concrete incorporating SG that illustrated the real case during accident occurrences. From this test, the penetration depth on the surface of concrete blocks can be observed clearly when subjected to low-velocity impact loads. The penetration depth can be measured by using a vernier calliper [22]. The energy absorption of concrete can be predicted by using the empirical formula by Hadipramana et al. [2], which is shown in equation (1).

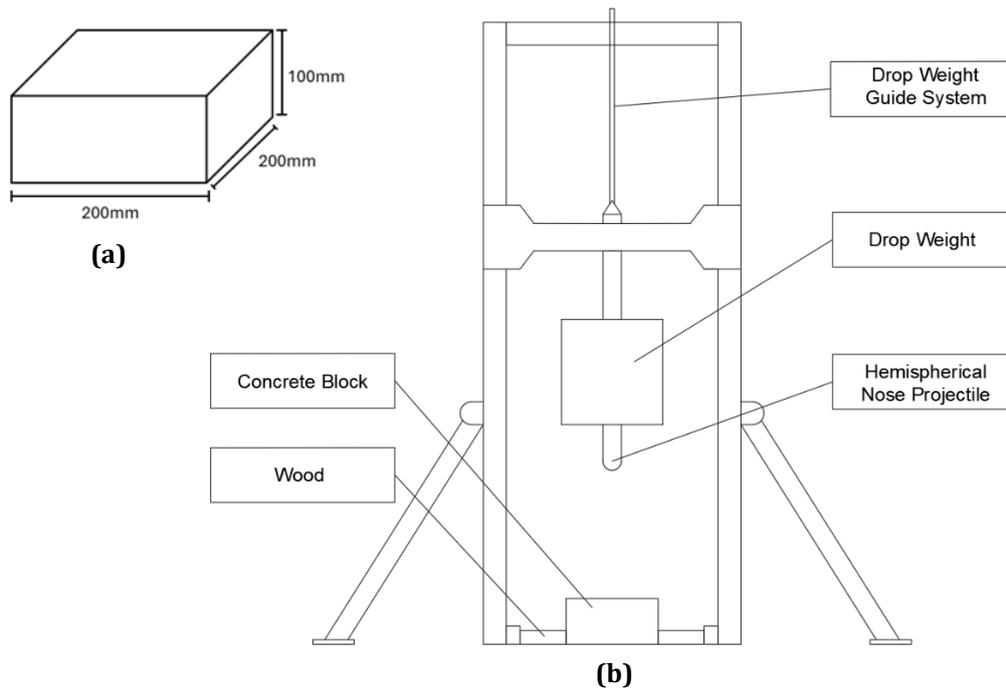


Fig. 2 Low-velocity impact test (a) Concrete block dimension; (b) Impact rigs

3. Results and Discussion

3.1 Compressive Strength Test

Figure 3 presents the compressive strength value for 7 and 28 days of concrete incorporating SG. The target strength for the concrete mix was set at 30MPa, following the standard Arahan Teknik (Jalan) 1/85 for concrete road barriers. The test was conducted using a Universal Testing Machine (UTM) by following BS EN 12390-3:2002. From the result obtained, all the specimens have passed the target strength, which indicates the concrete mix already meets the specific requirements. At 7 days, the compressive strength of mixture SG0 acts as control is 33.4 MPa. The compressive strength in all specimens in this study gradually decreases in the mixture SG10, SG20 and SG30. However, the compressive strength in mixture SG20 is nearest to the control specimens which is 32.8 MPa. On the other hand, the compressive strength decreases in the mixture SG10 and SG 30, which are 31.7 MPa and 30.9 MPa, respectively, which are lower than the control specimen. As for compressive strength at curing after 28 days, the pattern of the compressive strength is still the same as at 7 days. The control specimen compressive strength at 28 days in mixture SG0 is 43.5 MPa. The mixture SG20 slightly decreased in compressive strength at 42.1 MPa, which is higher than the control specimen. Meanwhile, the compressive strength in the mixture SG10 and SG30 decreased at 41.3 MPa and 40.7 MPa, respectively, which is less than the control specimen.

Based on the results, the compressive strength for all specimens is higher at 28 days of curing compared to 7 days of curing because the longer period of curing will increase the compressive strength of the specimen. Moreover, the presence of SG as a partial fine aggregate replacement in the specimen has decreased the compressive strength of the concrete compared to normal concrete. The result of compressive strength is lower in this study due to the smaller fineness of SG particles, which are smaller than the sand particles [23]. Hence, the presence of SG will cause a lesser appropriate gradient and shape to fill in the pores and void spaces in the mixed concrete. Therefore, the concrete containing SG produced lower amounts of compressive strength than the conventional concrete because of the fineness of SG particles [11]. The study by Phang et al. [23] stated that the optimum percentage of SG as a partial fine aggregate replacement in terms of compressive strength is 20%. In summary, the replacement of 20% SG as a partial fine aggregate replacement was the optimum percentage that could produce strength that is almost similar to the conventional concrete. In contrast, the replacement of 10% and 30% contributed to the undesired strength, which is the strength of the concrete is lower than the conventional concrete. It is indicated that the excessive amount of SG in concrete caused weaker bonding strength in the mixed concrete due to the fineness of SG particles, insufficient appropriate gradient and shape to fill the pores in the concrete [7].

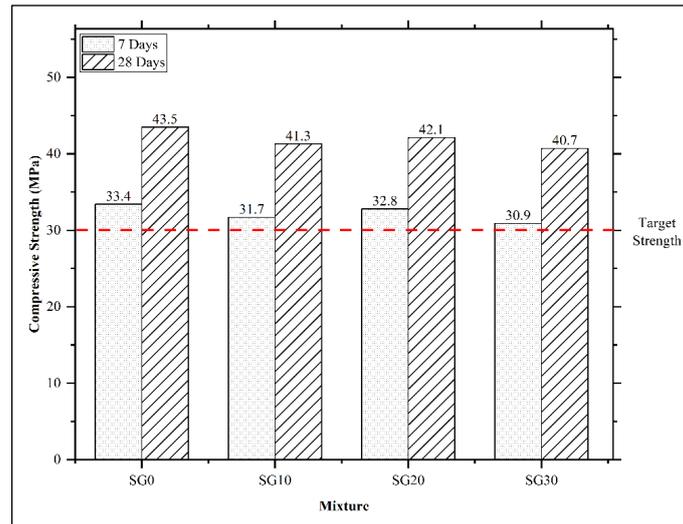


Fig. 3 Compressive strength

3.2 Low-Velocity Impact Test

A low-velocity impact test was conducted to examine the effect of an impactor on concrete blocks containing SG as a partial fine aggregate replacement. All 12 specimens were tested to measure crater diameter and penetration depth, with SG replacement proportions of 0%, 10%, 20%, and 30%, respectively. The primary goal of this experiment was to collect data on crater diameter and penetration depth to gain insight into the behaviour of concrete blocks with varying SG content under impact loading. For the impact mechanism, a 100 kg impactor was vertically dropped from a height of 0.3 m, achieving an impact velocity of 2.43 m/s, which is within the low-velocity range

3.2.1 Penetration Depth

Figure 4 illustrates the increase in penetration depth observed in the concrete block containing SG as a partial fine aggregate replacement. The penetration depth results from the free-fall impact tests conducted on concrete block specimens. The tests were performed on 28 days of curing concrete blocks, and the penetration depth was measured using a vernier calliper after an impact velocity of 2.43 m/s using the nose projectile. According to the results, the control mixture, SG0, acts as a conventional concrete and has a penetration depth of 1.74 mm. In comparison, the penetration depth gradually increased across specimens with SG replacement SG10, SG20, and SG30 exhibit penetration depth of 1.79 mm, 1.76 mm, and 1.84 mm, respectively. This indicates that the inclusion of SG in the concrete leads to an increase in penetration depth. Among all mixtures, SG30 has the highest penetration depth value. However, the SG20 mixture shows a penetration depth close to the SG0. This trend shows the acceptable penetration depth as compared to SG0.

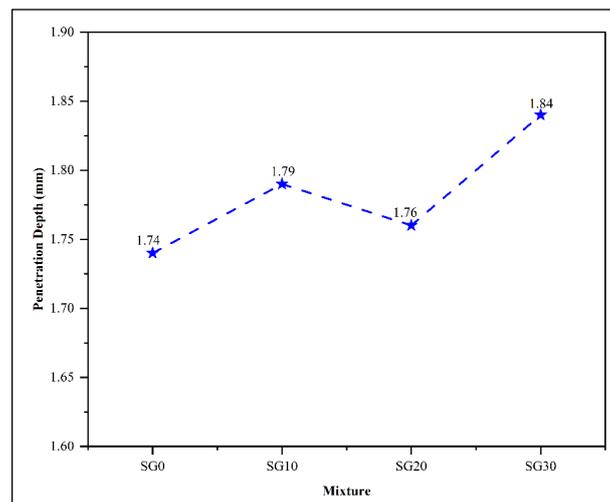


Fig. 4 Penetration depth of concrete block

3.2.2 Energy Absorption

Energy absorption was studied in order to predict the energy absorption characteristics of concrete incorporating SG when subjected to low-velocity impact loads. All 12 specimens were tested under 2.43 m/s impact velocity. The energy absorption of concrete containing SG is predicted by using the empirical formula in equation 1. Table 1 shows the average energy absorption of concrete blocks containing SG by using the energy absorption empirical formula. The mixture SG0 acts as a control and has the lowest energy absorption which is 1710.21 Nm. Based on the results findings, the energy absorption is gradually increased when adding SG as partial fine aggregate replacement in mixture SG10, SG20 and SG30. However, SG20 has the nearest value of energy absorption to SG0, which is 1729.83 Nm. Meanwhile, the highest energy absorption value is mixture SG30 which is 1805.04 Nm. This can be concluded that the SG as a partial fine aggregate replacement can influence the energy absorption of concrete blocks. Figure 5 presents the average energy absorption of concrete blocks incorporating SG as a partial fine aggregate replacement.

Table 1 Energy absorption of concrete blocks

Mixture	Sample	Impact Velocity (m/s)	Energy Absorption (Nm)	Average Energy Absorption (Nm)
SG0	1	2.43	1716.75	1710.21
	2		1628.46	
	3		1785.42	
SG10	1		1657.89	1759.26
	2		1932.57	
	3		1687.32	
SG20	1		1393.02	1729.83
	2		1952.19	
	3		1844.28	
SG30	1		1667.7	1805.04
	2		1814.85	
	3		1932.57	

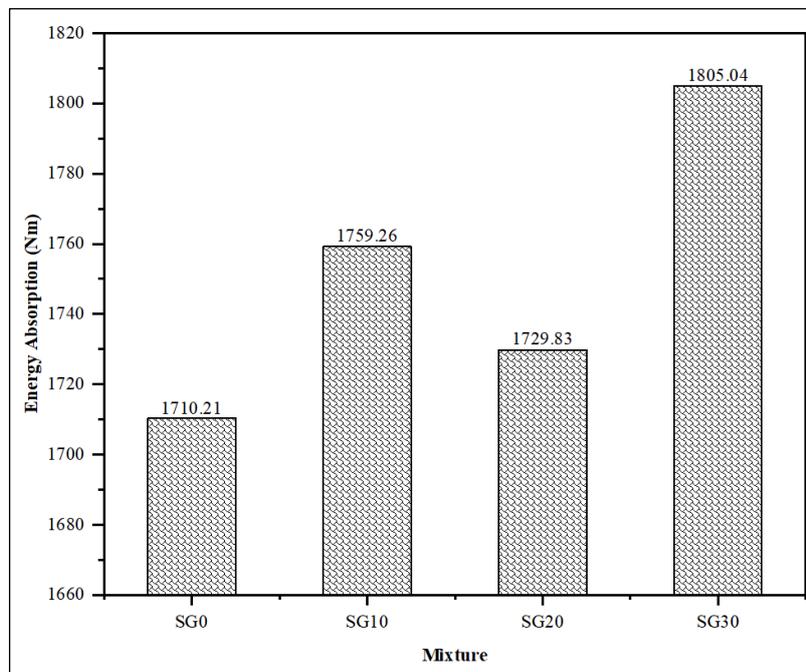


Fig. 5 Energy absorption of concrete blocks

3.3 Relationship Penetration Depth and Compressive Strength

Figure 6 shows the relationship between penetration depth and compressive strength in relation to the percentage of SG. The control specimen, SG0 containing 0% of SG, exhibited the highest compressive strength at 43.5 MPa and the lowest penetration depth at 1.74 mm. As SG content increased to 10%, 20%, and 30%, compressive strength progressively decreased due to the presence of SG. However, the 20% SG mixture displayed compressive strength closest to the control 0% SG, with a value of 42.1 MPa. Additionally, the penetration depth for the 20% SG mixture was slightly deeper than the control, measuring 1.76 mm. In contrast, while the 30% SG mixture had the highest penetration depth of 1.84 mm, it also had the lowest compressive strength, creating a significant gap from the control. Thus, the results indicate that using 20% SG as a partial fine aggregate replacement is the optimal percentage since it is high in compressive strength and penetration depth. Thus, the penetration depth was observed to be influenced by the compressive strength of the concrete [22]. This relationship suggests that higher compressive strength yields a more compact structure, resulting in lower penetration depth. However, SG's finer particle size relative to sand can reduce compressive strength, as excessive SG content may disrupt the ideal gradient and shape required to fill the pores and spaces within the concrete mix effectively [21][23].

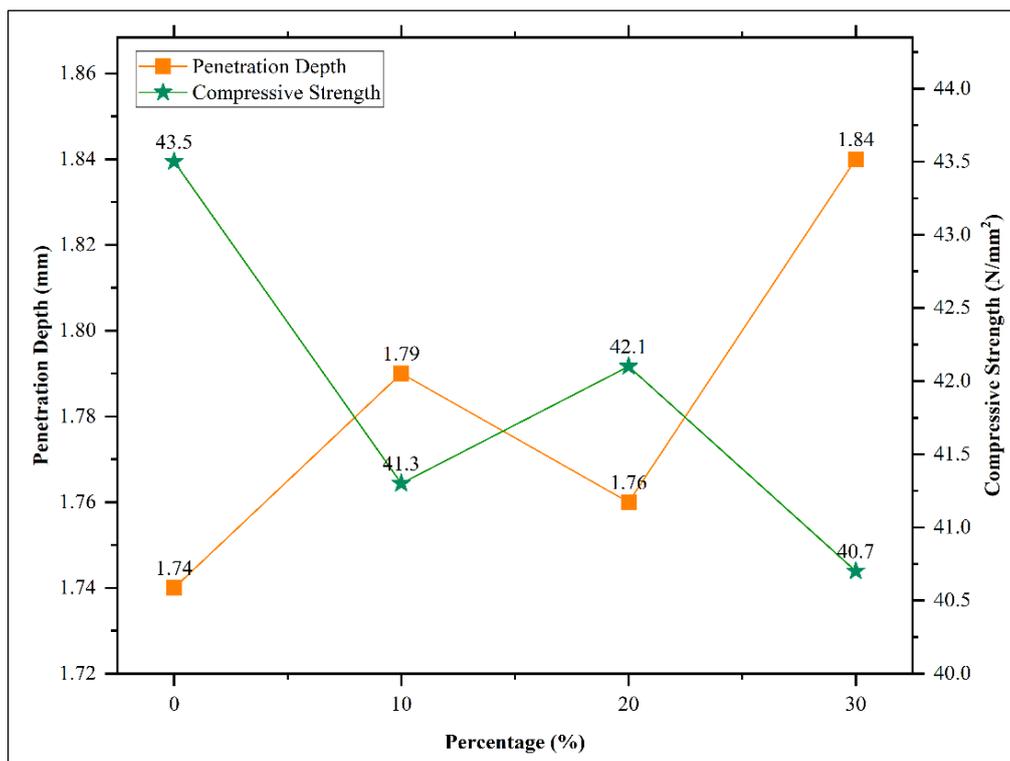


Fig. 6 Relationship between penetration depth and compressive strength toward percentage of SG

3.4 Relationship Energy Absorption and Compressive Strength

The graph in Figure 7 clearly shows an inverse relationship between energy absorption and compressive strength. As compressive strength decreases, the energy absorption of the concrete mixtures increases, highlighting a trade-off between these two key properties. This trend offers important insights into how the incorporation of SG as a partial fine aggregate replacement influences the behaviours of concrete in terms of energy absorption and compressive strength. The mixture with the percentage of 0% of SG acts as a control and conventional concrete has the highest compressive strength 43.5 N/mm² and the lowest energy absorption value is 1710.21 Nm among the other percentages. The presence of SG in the 10%, 20%, and 30% mixture as a partial fine aggregate replacement has gradually decreased compressive strength but increased energy absorption. On the other hand, the 30% mixture has the highest energy absorption value which is 1805.04 Nm and the lowest compressive strength which is 40.7 N/mm². Although the 30% mixture demonstrates excellent energy absorption capabilities, the compressive strength of the specimens falls significantly below the target strength. This indicates that concrete fails to meet the required performance criteria and does not fulfil its intended purpose. However, the 20% mixture has the closest value compared to conventional concrete in terms of compressive strength and energy absorption value which is 42.1 N/mm² and 1729.83 Nm, respectively.

The findings from the previous study also stated that the high compressive strength does not indicate excellent energy absorption [21]. Moreover, concrete with high compressive strength is characterized as brittle, exhibiting minimal deformation and experiencing sudden failure during the deformation process [21]. The low energy absorption is less effective to manage and withstand the mechanism of failure in the concrete. As a consequence, the vehicle will experience high fatality upon the impact on the concrete barrier since the concrete struggles to hold back itself from the sudden load. Therefore, 20% of SG as a partial fine aggregate replacement indicates the best percentage due to good energy absorption and compressive strength compared to 0% of SG.

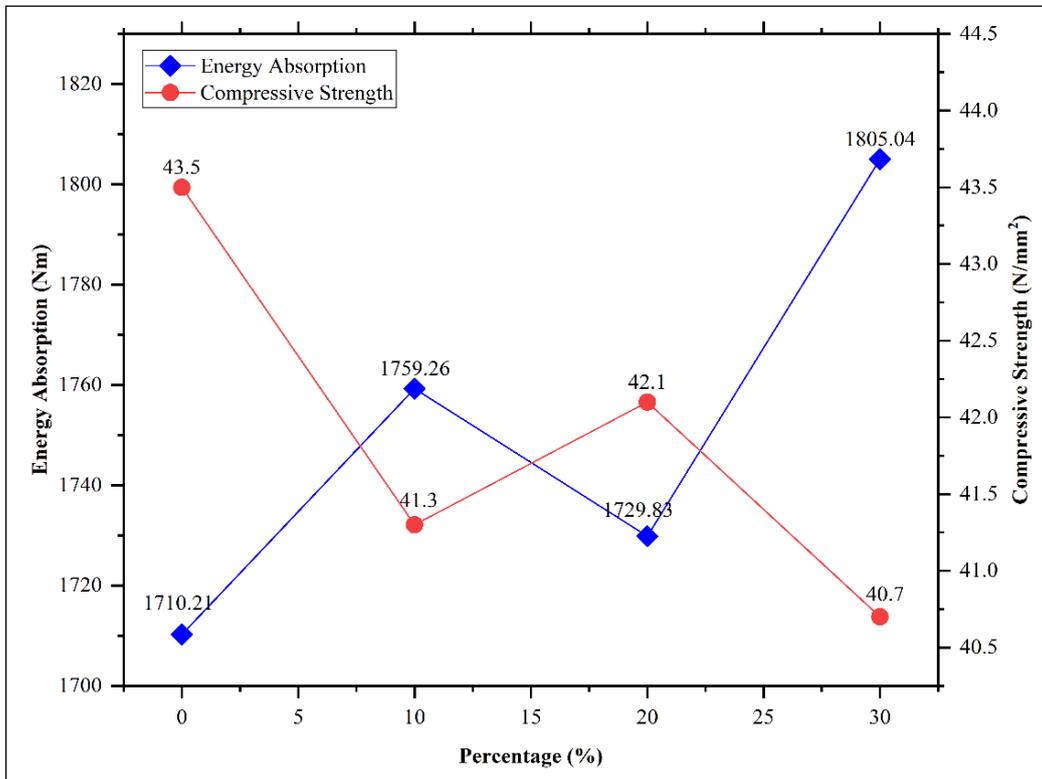


Fig. 7 Relationship between energy absorption and compressive strength

3.5 Relationship Energy Absorption and Penetration Depth

In Figure 8, the graph reveals a clear trend where energy absorption is directly proportional to penetration depth. This relationship suggests that as the penetration depth of the concrete increases, the capacity of concrete to absorb energy also rises. The control specimen, containing 0% SG and representing conventional concrete, exhibits the lowest penetration depth of 1.74 mm, while the energy absorption also has the lowest value, which is 1710.21 Nm when compared to the 10%, 20% and 30% of SG mixture. The results indicate that incorporating SG as a partial replacement for fine aggregate enhances both the penetration depth and energy absorption of the concrete. Among the tested mixtures, 30% of the SG mixture drastically increased in these properties, with a penetration depth of 1.84 mm and an energy absorption value of 1805.04 Nm. However, the 20% mixture has the closest value compared to conventional concrete in terms of penetration depth and energy absorption value, which are 1.76 mm and 1729.83 Nm, respectively.

Based on the results, it is clear that penetration depth and energy absorption are directly proportional, meaning that as penetration depth increases, the energy absorption value also increases. The relationship of these two variables is directly proportional, which is the penetration depth is proportional to energy absorption [16]. Furthermore, the penetration depth is significantly influenced by the velocity of the impactor, which plays a critical role in determining the penetration depth during the impact [2]. Considering these findings, the use of 20% SG as a partial fine aggregate replacement is identified as the optimal percentage. Therefore, 20% of SG as a partial fine aggregate replacement is indicated as an optimum percentage since it increases the penetration depth and energy absorption of concrete blocks than conventional concrete.

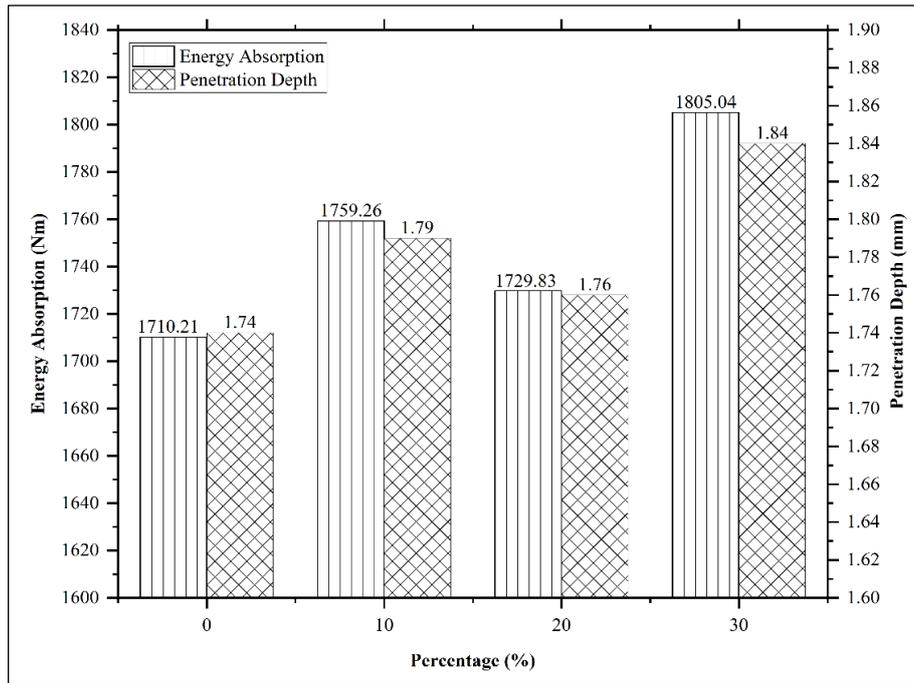


Fig. 8 Relationship between energy absorption and penetration depth

4. Conclusion

An experimental investigation into compressive strength was made with a proportion of SG of 0%, 10%, 20% and 30%, as well as evaluating the energy absorption of concrete containing SG under a low-velocity impact test at a fixed velocity of 2.43 m/s. Based on the analysis and discussion, several conclusions can be made:

- The data obtained by sieve analysis show that the SG particle size distribution falls within the lower and upper for fine aggregate grading limit, indicating SG is suitable for fine aggregate replacement.
- The compressive strength of concrete incorporating SG was discerned to be lower compared to control specimens at all stages of replacement.
- However, 20% of SG was the optimum percentage, which could produce strength almost similar to conventional concrete.
- The presence of SG in concrete blocks contributed toward the increase in penetration depth value.
- Energy absorption was inversely proportional to compressive strength.
- Although 30% of SG demonstrated excellent energy absorption capabilities, the compressive strength of the specimens falls significantly below the target strength, which indicates that concrete fails to meet the required performance criteria and does not fulfil its intended purpose.
- Thus, 20% of SG as a partial fine aggregate replacement indicates the best percentage due to good energy absorption and compressive strength compared to 0% of SG.
- Energy absorption was directly proportional to penetration depth.
- 20% of SG as a partial fine aggregate replacement is indicated as an optimum percentage since it increases the penetration depth and energy absorption of concrete blocks than control specimens.
- It can be asserted that 20% of SG has great potential to enhance energy absorption of concrete barriers in order to reduce fatality during vehicle impacts by absorbing more energy since it shows satisfactory results in terms of mechanical properties and energy absorption.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

References

- [1] Smarzewski, P., & Stolarski, A. (2022). Properties and Performance of Concrete Materials and Structures. MDPI, 12(9), 1–5. <https://doi.org/10.3390/cryst12091193>
- [2] Hadipramana, J., Aziz Abdul Samad, A., Mohamad, N., & Venny Riza, F. (2016). The energy absorption of modified foamed concrete with rice husk ash subjected to impact loading. ARPN Journal of Engineering and Applied Sciences, 11, 7437–7442. <https://www.researchgate.net/publication/305358609>
- [3] Ponnada, S., Sankar Cheela, V. R., & Gopala Raju, S. S. V. (2020). Investigation on mechanical properties of composite concrete containing untreated sea sand and quarry dust for 100% replacement of fine aggregate. Materials Today: Proceedings, 32, 989–996. <https://doi.org/10.1016/j.matpr.2020.06.203>
- [4] Mehrara Molan, A., Moomen, M., & Ksaibati, K. (2020). The impact of traffic barrier geometric features on crash frequency and injury severity of non-interstate highways. Journal of Safety Research, 75, 155–165. <https://doi.org/10.1016/j.jsr.2020.09.005>
- [5] Shen, Weiguo, Chuan Zhang, Zhifeng Yang, Liu Cao, Zhenguo Yang, & Bo Tian. (2014). Investigation on the Safety Concrete for Highway Crash Barrier. Construction and Building Materials, 70, 98–394.
- [6] Lim, N. H. A. S., Alladin, N. F. N., Mohammadhosseini, H., Ariffin, N. F., & Mazlan, A. N. (2020). Properties of Mortar Incorporating Spent Garnet as Fine Aggregates Replacement. International Journal of Integrated Engineering, 12(9), 96–102. <https://doi.org/10.30880/ijie.2020.12.09.012>
- [7] Jamaludin, N. F. A., Muthusamy, K., Isa, N. N., Md Jaafar, M. F., & Ghazali, N. (2021). Use of spent garnet in industry: A review. Materials Today: Proceedings, 48, 728–733. <https://doi.org/10.1016/j.matpr.2021.02.210>
- [8] Mokhatar, S. N., Yusoff, A. R. M., Budiea, A. M. A., Hakim, S. J. S., & Jaini, Z. M. (2022). A Review: Study on Spent Garnet as Construction Material. International Journal of Integrated Engineering, 14(5), 73–80. <https://doi.org/10.30880/ijie.2022.14.05.008>
- [9] Ghasan Fahim Huseien, Abdul Rahman Mohd.Sam, & Shah Kwok Wei. (2019). Utilizing spend garnets as sand replacement in alkali-activated mortars containing fly ash and GBFS. Construction and Building Materials, 225, 132–145.
- [10] Kittipong Kunchariyakun, & Patimapon Sukmak. (2020). Utilization of garnet residue in radiation shielding cement mortar. Construction Building and Materials, 10, 120122.
- [11] Muttashar, H. L., Ariffin, M. A. M., Hussein, M. N., Hussin, M. W., & Ishaq, S. Bin. (2018). Self-compacting geopolymer concrete with spend garnet as sand replacement. Journal of Building Engineering, 15, 85–94. <https://doi.org/10.1016/j.jobbe.2017.10.007>
- [12] Aletba, S. R., Hassan, N. A., Aminudin, E., Putra Jaya, R., & Hussein, A. A. (2018). Marshall Properties of Asphalt Mixture Containing Garnet Waste. Journal of Advanced Research in Materials Science, 43, 22–27.
- [13] Muttashar, H. L., Hussin, M. W., Ariffin, M. A. M., Mirza, J., Hasanah, N., & Shettima, A. U. (2017). Mechanical properties of self-compacting geopolymer concrete containing spent garnet as replacement for fine aggregate. Jurnal Teknologi, 79(3), 23–29. <https://doi.org/10.11113/jt.v79.9957>
- [14] Muttashar, H. L., Ali, N. Bin, Mohd Ariffin, M. A., & Hussin, M. W. (2018). Microstructures and physical properties of waste garnets as a promising construction materials. Case Studies in Construction Materials, 8, 87–96. <https://doi.org/10.1016/j.cscm.2017.12.001>
- [15] Chik, W. M. E. K. W., Mokhatar, S. N., Othman, N. H., Budiea, A. M. A., & Muthusamy, K. (2024). The Exploration of the Characteristics of Concrete Incorporating Ultrafine Coal Bottom Ash and Spent Garnet. Journal of Advanced Research in Applied Sciences and Engineering Technology, 36(2), 164–175. <https://doi.org/10.37934/araset.36.2.164175>
- [16] Kadir, M. A., Niza Mokhatar, S., Najwa, A., & Mutalib, A. (2022). Energy Absorption of Modified Rubberized Concrete Block Under Low Velocity Impact Loads. Recent Trends in Civil Engineering and Built Environment, 3(1), 420–426. <https://doi.org/10.30880/rtcebe.2022.03.01.044>
- [17] BS 882:1992. Specification for aggregates from natural sources for concrete. British Standard Institution Publications.

- [18] BS EN 12390-3:2019. Testing hardened concrete - Part 3: Compressive strength of test specimens. British Standard Institution Publications.
- [19] BS EN 22248:1993. Packaging - Complete, filled transport packages - Vertical impact test by dropping. British Standard Institution Publications.
- [20] Rahmat, M. S., Mokhtatar, S. N., Razali, B. A., Hadipraman, J., & Hakim, S. J. S. (2023). Numerical Modelling of Impact Loads on RC Beams Utilizing Spent Garnet as a Replacement for Fine Aggregate. *Journal of Advanced Research in Applied Mechanics*, 107(1), 41–54. <https://doi.org/10.37934/aram.107.1.4154>
- [21] Mokhtatar, S. N., Anis, N., Mutalib, N. A., Asmawi, M., Ayob, M., Mokhtatar, A., Budiea, A., Jaini, Z. M., Kamarudin, A. F., Soffi, M., & Noh, M. (2021). Energy Absorption of Concrete Containing Waste Crumb Rubber and Rice Husk Ash (RHA) Under Impact. *MCRJ Special Issue*, 13(2), 142–156.
- [22] Hadipramana, J., Aziz Abdul Samad, A., Niza Mokhtatar, S., Venny Riza, F., Mohamad, N., & Yusuf Mohd Wahab, M. (2017). An investigation of Crater Diameter on Plain Slab Foamed Concrete Rice Husk Ash (FCRHA) Exposed to Low Impact Loading. *MATEC Web of Conferences*, 1–8. <https://doi.org/10.1051/mateconf/201710302025>
- [23] Phang, Z. Q., Niza Mokhtatar, S., Mokhtatar, A., & Budiea, A. (2022). Effects of Spent Garnet on The Compressive and Flexural Strengths of Concrete. *Recent Trends in Civil Engineering and Built Environment*, 3(1), 1948–1957. <https://doi.org/10.30880/rtcebe.2022.03.01.216>