RECENT TREND IN CIVIL ENGINEERING AND BUILT ENVIRONMENT
e-ISSN: 2773-5303

RTCEBE

Vol. 6 No. 2 (2025) 38-51
https://publisher.uthm.edu.my/periodicals/index.php/rtcebe

A Study on the Propagation of Cracks in A Reinforced Concrete Beam Incorporating Spent Garnet Subjected to Repeated Impact Loads

Maizatul Najihah Basirun[1], Shahrul Niza Mokhatar[2]*

[1] *Faculty of Civil Engineering and Built Environment,*
Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, MALAYSIA

[2] *Structural Dynamics and Computational Engineering, Faculty of Civil Engineering and Built Environment,*
Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author: shahruln@uthm.edu.my

DOI: https://doi.org/10.30880/rtcebe.2025.06.02.005

Article Info

Received: 13 January 2024
Accepted: 15 April 2024
Available online: 30 December 2025

Keywords

Propagation of Cracks, Reinforced Concrete (RC) Beam, Spent Garnet, Compressive Strength, Repeated Impact Loads

Abstract

In recent decades, global development has significantly impacted the environment due to the escalating demand for natural sand, a crucial component in concrete production. The exploitation of non-renewable sand resources through mining raises concerns about erosion, negatively affecting ecosystems, and altering hydrogeological and hydrological systems. The use of garnet from surface cleaning processes in the shipping industry, often discarded as waste, contributes to pollution. To address sustainability concerns, this study explores the use of spent garnet as a replacement for sand in concrete production. Concrete cubes with a size of 100 × 100 × 100 mm varying in spent garnet content 0%, 10%, 20%, 30%, and 40% exhibit optimal strength at a 40% replacement level, as demonstrated by compressive strength tests at 7 and 28 days. Repeated impact load using a 100 kg impact weight dropped with a height of 0.5 m on beam specimens measuring 120 × 150 × 800 mm with a velocity of 3.13 m/s reveal that the resulting crack pattern is influenced by the amount of garnet used, with fewer flexural and shear cracks observed at the 40% spent garnet level. In conclusion, the utilization of spent garnet has the potential to be a sustainable material, offering an alternative to reduce reliance on natural sand in concrete mixes.

1. Introduction

In recent years, Malaysia's construction sector has experienced significant growth, contributing to the country's overall economic progress. The focus on infrastructure development and urbanization has spurred construction activities, as highlighted by Alaloul et al. (2021), emphasizing the global impact of the building industry on economic growth. Concrete, recognized as a widely utilized creation second only to water, is celebrated for its cost-effectiveness, strength, and durability (Thunga & Das, 2020). However, the construction sector raises environmental concerns due to the material used in concrete production, with global concrete production projected to be four-fold by 2050 (Omar & Muthusamy, 2022). The demand for construction minerals, particularly aggregates, has surged, leading to concerns about the environmental impact of river sand exploitation.

Researchers, including Ab Kadir et al. (2019), propose the use of spent garnet as a sustainable alternative to sand in concrete mixes, addressing issues such as reducing landfill space and minimizing river sand usage.

Despite the potential benefits, the study highlights the importance of evaluating the effectiveness of incorporating used garnet in concrete, particularly in understanding crack propagation under repeated impact loading conditions. These tests aim to determine the durability of concrete structures and evaluate their capacity to withstand additional loads. Structures and components often face repetitive impact forces throughout their operational lifespan, which can take various forms and arise from different causes. Understanding these factors is crucial for ensuring the successful integration of used garnet in concrete applications.

The growing demand for sand in industry and construction poses environmental challenges as sand and soil mining cause significant harm, leading to the depletion of non-renewable natural resources (Saviour, 2012). In 2010, Malaysia's substantial consumption of natural aggregate, primarily sand and gravel, reached 2.76 billion metric tons, with variations in consumption across states (Ali, 2017). Concurrently, Huseien et al. (2019) highlight the environmental impact of the Malaysian shipbuilding industry's disposal of thousands of tonnes of garnets annually. The waste, including garnet waste, old paint, and oil, poses risks to the surrounding ecosystem, necessitating recycling or repurposing to prevent contamination of land and water resources. Additionally, the need to ensure structural safety under impact loading conditions is increasing. Throughout their lifespan, reinforced concrete (RC) structures face various impact loads due to unavoidable or natural hazards, such as impacts from vehicles, ships, falling objects resulting from upper-floor failure, and falling rocks on rock sheds. Understanding how reinforced concrete beams behave under repeated impact loads is crucial for safety and risk assessment. This knowledge enables the evaluation of the performance and resilience of structures exposed to impact events.

Spent garnet, discarded abrasive material posing environmental risks in landfills, can address ongoing issues related to sand exploitation for development by serving as a replacement (Budiea, 2023). Recent research highlights the Malaysian shipbuilding industry's substantial annual acquisition of garnets, a significant portion of which is discarded as waste (Huseien et al., 2019). In contrast, the Malaysian Marine Heavy Industry (MMHE) imported around 2000 tons of garnet for sandblasting ships in 2013, contributing to waste pollution and environmental concerns when disposed of as spent garnet (Phang et al., 2022). Concrete, the second most utilized substance globally, faces escalating demand, especially in densely populated countries like India and China. This demand, causing depletion of natural resources and environmental imbalances from extensive river sand mining, necessitates exploring alternatives such as spent garnet as a viable choice for fine aggregate (Jamaludin et al., 2021) (Thunga & Das, 2020).

Phang et al. (2022) conducted a sieve analysis on spent garnet and sand, revealing well-graded patterns in both materials, as depicted in Figure 1. The grading coefficients for sand and spent garnet were 1.09 and 1.07, respectively, both exceeding 1.0, which is considered theoretically well-graded. This implies that the particle grading of spent garnet meets the standards for fine aggregates used in concrete production.

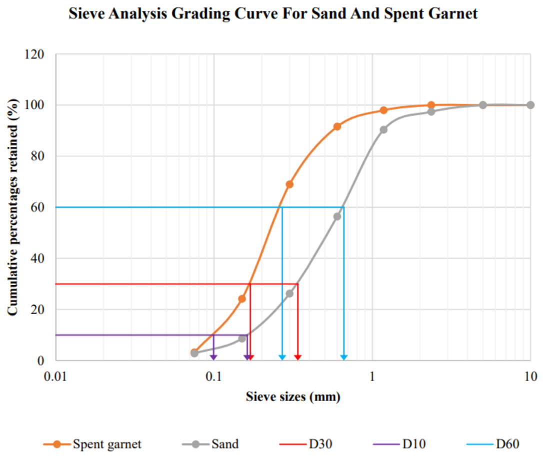


Fig. 1 *Sieve analysis grading curve for sand and spent garnet (Phang et al., 2022)*

In a study by Phang et al. (2022), a slump test was conducted to assess the workability and consistency of freshly mixed concrete. The control sample exhibited a slump of 35mm, falling within the designed slump range of 30mm to 60mm. As the percentage of spent garnet in the fresh concrete increased, the slump also increased, ranging from 50mm to 85mm. This increase in slump was attributed to the high density of spent garnet, which negatively impacted its ability to maintain consistency. However, the study indicated that the addition of increasing amounts of spent garnet led to an enhancement in the workability of the fresh concrete.

In a study conducted by Kadir et al. (2019), the replacement of river sand with spent garnet in concrete demonstrated increased strength at 7 and 28 days, with the strength reaching up to 40% as indicated in Figure 2. At 28 days, the strengths for high-strength spent garnet concrete (HSSGC) at 20% and HSSGC at 40% increased by 3.77% and 6.02%, respectively. The enhanced strength for HSSGC at 40% was attributed to the fine particles of spent garnet filling voids, reinforcing the concrete. However, exceeding 40% resulted in reduced strength as spent garnet, classified as a poorly graded aggregate, caused degradation in bonding with cement. Consequently, the study identified 40% spent garnet as the optimal proportion for maximizing concrete strength.

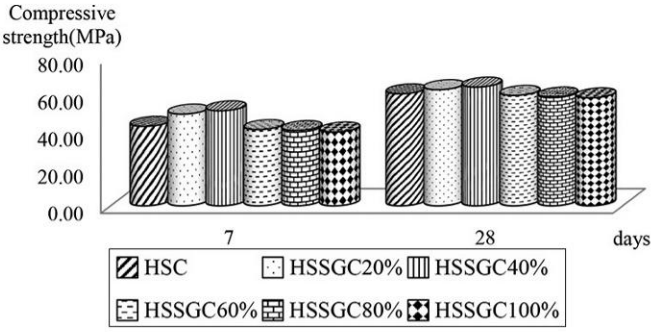


Fig. 2 *Compressive strength for high-strength spent garnet concrete (HSSG) for all specimens at 7 and 28 days (Kadir et al., 2019b)*

The drop weight impact test, commonly used to examine the impact behaviour of RC beams, involves measuring the impact force between the drop weight and the beam using a load cell while recording the displacement at midspan to assess dynamic responses. The failure mode of RC beams under impact loads, such as flexure, flexure-shear, or local punching shear failure, varies based on loading rates, load-carrying capacities, and peak forces (Li et al., 2021). Madjlessi et al. (2021) conducted drop weight testing on slender reinforced concrete beams, subjecting them to repeated impacts by a 124 kg steel drop mass. The study emphasized that data collected from impact tests, once the experimentally established crack pattern indicating flexural capacity is reached, should not be considered helpful for real-world structural applications.

In this study, spent garnet was used as the partial alternative material for sand in the concrete mixture. This study aimed to find the optimal ratio of spent garnet to replace sand in concrete mixes. It also investigated the propagation of cracks by conducting repeated impact load testing by dropping a 100 kg impact weight onto beam specimens. The study explored the potential advantages of using sustainable alternatives. It contributed to material optimization by evaluating the effectiveness of spent garnet in enhancing structural performance and reducing the environmental impact of concrete production.

2. Methodology

The methodology underscored several key strategies and techniques essential for achieving the study's objectives. The following sections provide explanations for the preparation of materials, mix design, and laboratory tests employed in this research.

2.1 Materials Preparation

In Malaysia, Ordinary Portland Cement (OPC) was extensively utilized in concrete production, serving as a crucial binding agent that bound the ingredients together. The measured amount of OPC was added to the aggregate mixture, playing a pivotal role in the production of concrete. Water's significant role in concrete mixtures involves facilitating cement hydration, a chemical reaction crucial for creating a robust structure. The precise measurement of water, gradually added during the mixing process, was essential to attain the desired workability and strength. Achieving a homogeneous mixture through careful regulation ensured consistency and the production of strong, durable concrete during construction.

Fine aggregates played a vital role in improving concrete packing by filling gaps between larger coarse aggregates, thus reducing the required cement paste. Clean, impurity-free, and properly graded fine aggregates were essential for optimal concrete performance. Before incorporation into the concrete mix, the fine aggregate underwent sieving to ensure a uniform particle size distribution, contributing to consistent properties and workability. The inclusion of coarse aggregates involved thorough inspection to ensure cleanliness and freedom from impurities. Once successfully inspected, accurately measured 20 mm coarse aggregates were added to the concrete mixture according to specified proportions.

In southern Malaysia, the MMHE company supplied spent garnet, utilized as a partial replacement for fine aggregates. The spent garnet underwent sieving using a 4.75 mm sieve before being added to the concrete mixture. The material was weighed based on the quantity specified by the Department of Environment (DOE), with various percentages used in this study, including 0%, 10%, 20%, 30%, and 40%. The spent garnet material, obtained from Boustead Naval Shipyard Sdn. Bhd, Lumut, Perak, is depicted in Figure 3 in the laboratory setting. This sustainable approach to waste material utilization contributes to the study's environmental considerations and potential for concrete mix optimization.

Fig. 3 *Spent garnet at Advanced Materials Engineering Laboratory UTHM*

2.2 Sample Preparation

This study focused on examining the mechanical properties of spent garnet in plain concrete by conducting tests on both concrete cubes and reinforced concrete (RC) beams. Compression tests were employed to assess the behaviour of different concrete mixes, and the study also investigated the performance of concrete containing spent garnet under low-velocity impact conditions. Specifically, a specially prepared beam specimen was subjected to impact loads to evaluate its response. Tables 1 and 2 detailed the overall sample preparation for the study, encompassing varying percentages of spent garnet.

Table 1 *Total of cube samples for each per cent*

Duration of compressive strength (days)	7 days and 28 days				
Percentage of spent garnet (%)	0%	10%	20%	30%	40%
Samples of cube	6	6	6	6	6

Table 2 *Total of beam samples for each per cent*

Duration of compressive strength (days)	28 days				
Percentage of spent garnet (%)	0%	10%	20%	30%	40%
Samples of beam	3	3	3	3	3

The design of RC beams followed Eurocode 2 (EC2) guidelines, involving steps like determining design loads, selecting codes, and establishing dimensions based on span length and load capacity. Calculations assessed bending moment, shear forces, and deflection. Reinforcement design considered necessary amounts, bar specifications, spacing, and local building codes. The design calculations revealed a beam with two tension bars (8 mm) and link bars (6 mm). Figure 4 illustrates the RC beam size.

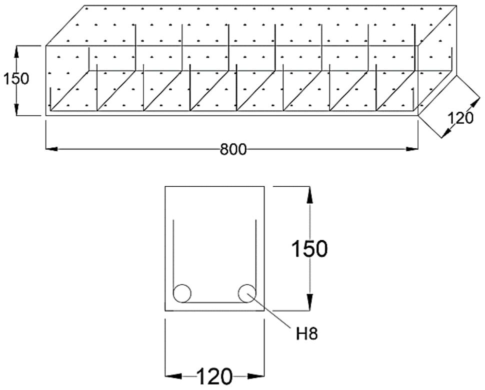


Fig. 4 *RC beam illustration*

In this study, the design of experiment (DOE) method was employed for concrete mix design, systematically adjusting material proportions to identify the optimal combination for achieving the desired performance, targeting a compressive strength of 35 MPa by day 28. Concrete volume calculations were performed to assess the appropriateness of proportions among all constituent elements, and the specific quantities for concrete cube and beam specimens were detailed in Tables 3 and 4.

Table 3 *Mix design for cube*

Parameter	Percentage of spent garnet (%)				
	0%	10%	20%	30%	40%
Cement (kg)	2.38	2.38	2.38	2.38	2.38
Water (kg or litres)	1.14	1.14	1.14	1.14	1.14
Fine aggregate (kg)	4.25	3.82	3.40	2.97	2.55
Coarse aggregate (kg)	6.64	6.64	6.64	6.64	6.64
Spent garnet (kg)	0	0.43	0.85	1.28	1.70

Table 4 *Mix design for beam*

Parameter	Percentage of spent garnet (%)				
	0%	10%	20%	30%	40%
Cement (kg)	17.11	17.11	17.11	17.11	17.11
Water (kg or litres)	8.21	8.21	8.21	8.21	8.21
Fine aggregate (kg)	30.59	27.53	24.47	21.41	18.35
Coarse aggregate (kg)	47.82	47.82	47.82	47.82	47.82
Spent garnet (kg)	0	3.06	6.12	9.18	12.24

2.3 Concrete Mixing for Sample Preparation

The steps involved in casting concrete specimens typically included mixing and casting the concrete, slump test, and curing.

2.3.1 Mixing and Casting

Different percentages of spent garnet, ranging from 10% to 40%, were mixed with fine aggregate and ordinary Portland cement. The components were carefully blended with water to achieve the desired consistency. Subsequently, the well-mixed concrete mixture was poured into cube moulds and beam formwork, ensuring uniform filling of all corners and spaces, as depicted in Figure 5 for concrete cubes and Figure 6 for beam samples. Special attention was given to ensuring even distribution and adequate compaction of the concrete, minimizing voids or air pockets. All cube samples maintained consistent dimensions, measuring 100 mm in length, width, and height. Likewise, the 15 beam specimens shared uniform measurements of 800 mm in length, 120 mm in width, and 150 mm in height.

(a) **(b)**

Fig. 5 *Concrete cube for (a) 0% of spent garnet; (b) 10% of spent garnet*

(a) **(b)** **(c)** **(d)**

Fig. 6 *Beam sample for (a) 0%; (b) 10% and 20%; (c) 30%; (d) 40% of spent garnet*

2.3.2 Slump Test

A slump test was conducted to gain insights into the consistency of the freshly mixed concrete and its ability to be effectively placed and compacted during construction. The cone used for the test had a height of 300 mm, an upper diameter of 100 mm, and a lower diameter of 200 mm. The concrete slump test, following the guidelines of BS 1881 - Part 102:1983, involves several steps. To perform a slump test on fresh concrete, first, clean the inside cone and place it on a flat surface. Fill the cone with concrete in three layers, tamping each layer 25 times. After rodding the top layer, level the concrete with a trowel or tamping rod. Measure the slump by determining the difference in height between the mould and the highest point of the specimen. In this example as shown in Figure 7, the slump test resulted in a slump of 35mm for a 30% spent garnet mix in fresh concrete.

Fig. 7 *Slump test for 30% of spent garnet at Advanced Material Laboratory UTHM*

2.3.3 Curing

All specimens were removed from the moulds and underwent a curing process 24 hours after being cast. The 7-day curing period was crucial for evaluating initial strength development, while the 28-day curing period assessed long-term strength and durability. The curing process involved placing concrete cubes inside water-filled barrels. Figure 8 shows the curing process of concrete cubes at the Advanced Materials Engineering Laboratory UTHM. It depicts the placement of the concrete cube inside a water-filled barrel.

Fig. 8 *Curing tank at Advanced Materials Engineering Laboratory UTHM*

2.4 Laboratory Tests

The tests are carried out to study the effects of spent garnet as a fine aggregate replacement on the concrete mixture involving compressive strength test and repeated impact load test.

2.4.1 Compressive Strength Test

In this study, all cube specimens were extracted after 7 and 28 days of curing. The compressive strength testing, following BS EN 12390-3-2009 guidelines, involved several steps. The specimen was removed from the curing tank and weighed before undergoing compressive testing. The testing surface was flat, and the specimen position was centred between the compression plates. The load was gradually increased until the maximum load achieved during the test was recorded. Samples were placed in a compression machine with surface contacting plates, as shown in Figure 9.

Fig. 9 *Compressive machine test at Materials Engineering Laboratory UTHM (FKAAB)*

2.4.2 Repeated Impact Load Test

The impact load test evaluated the behaviour of an RC beam under real-world impact loads, focusing on cracking, a specific type of failure that occurs when cracks form and propagate within the beam due to applied load. The testing parameters included a velocity of 3.13 meters per second (m/s), a drop height of 0.5 meters (m) that has been calculated from the physics formula, and an applied load of 100 kilograms.

The test was performed by arranging the support system and positioning it according to specified dimensions, and the beam specimen was placed on it, ensuring proper alignment. Next, a thorough check of all component connections was conducted to ensure their proper functioning, prioritizing stability and safety. Finally, the drop weight was raised to the desired height, measured accurately, and released to fall onto the specimen until failure. These steps were implemented systematically to guarantee the reliability and efficiency of the test. Figure 10 displays the experimental apparatus setup at the UTHM laboratory, and Figure 11 illustrates the impact load test.

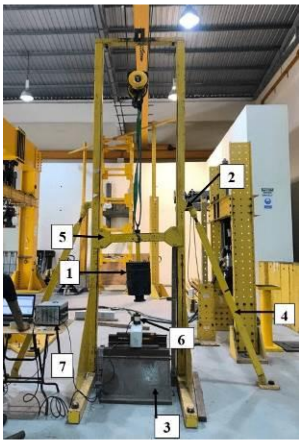


Fig. 10 *Experimental apparatus setup at Jamilus Research Centre UTHM (1) Steel drop weight 100kg, (2) Steel frame (3) Beam support (4) Steel rig bracing, (5) Steel weight support 34kg (6) Load cells (7) Data logger*

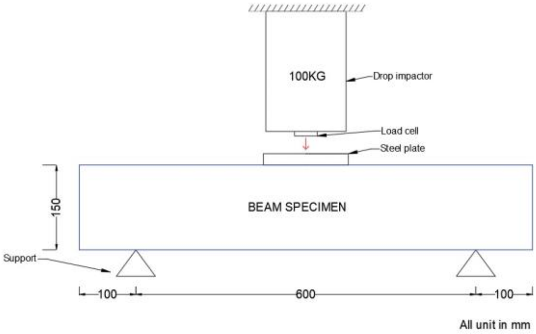


Fig. 11 *Impact load test illustration*

3. Results and Discussion

3.1 Compressive Strength

Concrete cubes measuring 100 x 100 mm are subjected to increasing compressive force until they fracture, aiming to assess their strength. The 7-day compressive strength is an early-age performance measure for concrete. According to JKR standards, early compressive strength requirements are 70% (Standard Specifications for Building Works, 2014). While the 28-day test is widely accepted as the standard duration for evaluating the concrete's ultimate strength and its capacity to withstand external forces over a prolonged period. Additionally, the 28-day strength acts as a benchmark for quality control in construction projects. It could be essential to modify the mix or the curing conditions if the concrete does not reach the desired compressive strength after 28 days.

Table 5 *The compressive strength at the age of 7 and 28 days*

Percentage replacement of spent garnet	Compressive strength (MPa)	
	7 Days	28 Days
0%	28.47	52.45
10%	28.27	37.54
20%	31.41	38.31
30%	31.64	42.34
40%	37.00	52.96

The result of compressive strength of concrete cube specimens at 7 and 28 days were tabulated in Table 5 above. The result exhibits a consistent upward trend as the percentage of spent garnet replacement in concrete increases. At 0% replacement at 7 days of aging, the average compressive strength is 28.47 MPa, rising to 37.00 MPa at 40% replacement, indicating a positive influence of spent garnet on concrete strength. However, there is some variability within each replacement percentage, suggesting factors like material distribution and curing conditions contribute to strength variations. Previous research by Kadir et al. (2019) supports the idea that up to 40% spent garnet replacement enhances compressive strength. In this study, concludes that 40% replacement is optimal, as the concrete mix achieves a maximum strength of 37.00 MPa, while the mix with 10% replacement has the lowest strength at 28.27 MPa. This highlights the potential of spent garnet as a sand replacement, offering possibilities for sustainable concrete production and reduced reliance on natural sand (Budiea et al., 2023).

At the age of 28 days, the control specimen achieved a strength of 52.45 MPa. Subsequently, there is a decrease in compressive strength at 10% spent garnet replacement. However, the strength starts increasing from 20% spent garnet replacement, reaching values of 38.31 MPa for 20%, 42.34 MPa for 30%, and 52.96 MPa for 40%. Overall, the optimal average compressive strength is observed at 40% spent garnet replacement, reaching 52.96 MPa.

In conclusion, the increasing compressive strengths by day 28, especially for the 40% replacement mix, suggest that spent garnet particles fill voids, enhancing the concrete's strength and compactness (Kadir et al., 2019). This implies that incorporating wasted garnet as a partial replacement for sand improves the concrete's resistance to compressive stresses. Diverse responses across various replacement percentages highlight a significant relationship between spent garnet quantity and compressive strength.

3.1.1 Comparison of Compressive Strength

In Figure 12, demonstrated in the graph, the comparison of compressive strength values at 7 and 28 days reveals significant improvements in the control group (0% replacement) from 28.47 MPa at 7 days to 52.45 MPa at 28 days. With spent garnet replacement, there is a minor decrease at 10% but a consistent increase at 20%, 30%, and 40% replacements, reaching a peak at 40% with 52.96 MPa at 28 days.

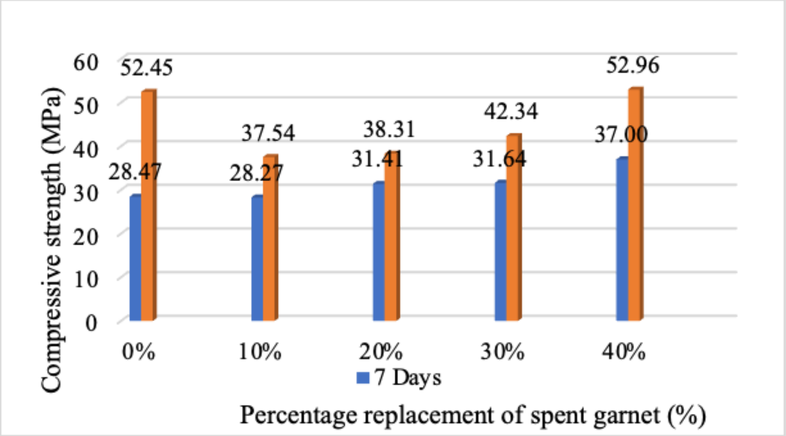


Fig. 12 *Comparison of compressive strength at aging day (7 and 28 days)*

To put it briefly, the spent garnet material can serve as a suitable replacement for fine aggregates in concrete mixtures, with an optimum replacement rate of 50% (Lim et al., 2020). Also, based on another researcher, it was found that utilizing 40% of spent garnet as an aggregate material resulted in higher bond strength when compared to high-strength concrete (Khiyon, 2018). These findings suggest that incorporating spent garnet, especially at higher replacement levels, positively impacts concrete compressive strength, providing valuable insights for potential optimizations in practical concrete formulations.

3.2 Repeated Impact Load Test

Five different types of RC beams measuring 120 × 150 × 800 mm were subjected to repeated load impacts, with varying percentages of spent garnet in the concrete mix containing 0%, 10%, 20%, 30%, and 40%. The testing parameters included a velocity of 3.13 meters per second (m/s), a drop height of 0.5 meters that has been calculated from the physics formula, and an applied load of 100 kilograms (kg).

3.2.1 Crack Propagation on RC Beam

The black marker indicates the crack pattern after the first impact loading, while the red marker highlights new fracture lines after the second impact and a blue marker indicates the crack pattern after the third impact.

In Figure 13, the black marker shows vertical flexural cracks from top to bottom during the first impact, caused by bending loads. In the second impact, the red marker indicates additional cracks without spent garnet, suggesting bending load failure. The third impact, highlighted in blue, reveals new fractures, and enlarged existing cracks, indicating vulnerable areas prone to failure. This analysis helps understand the beam's response to successive loading, crucial for assessing material durability. With no spent garnet replacement, the concrete behaves conventionally, and the structural response aligns with expectations.

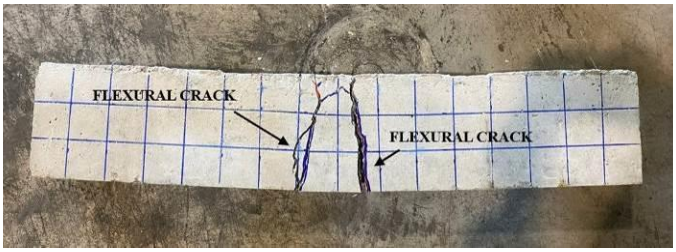


Fig. 13 *Final crack patterns after first, second and third impacts on RC beam with 0% spent garnet replacing sand*

Results with 10% spent garnet are displayed in Figures 14 and 15. In Figure 15, flexural cracks are apparent after the first, second, and third impacts. The presence of 10% spent garnet does not significantly alter the beam's structural response, suggesting minimal change in concrete mix properties. However, with further loading, the beam shows increased bending compared to its initial load, as seen in Figure 14, demonstrating a notable change in the beam's behaviour compared to its condition before conducting the impact loading test.

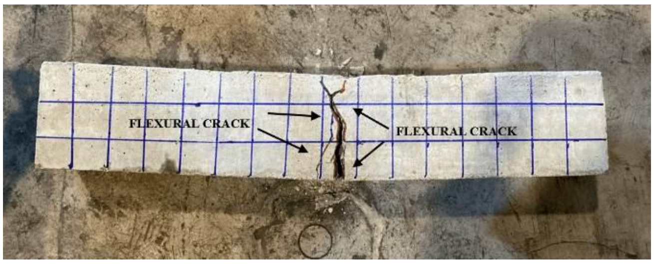
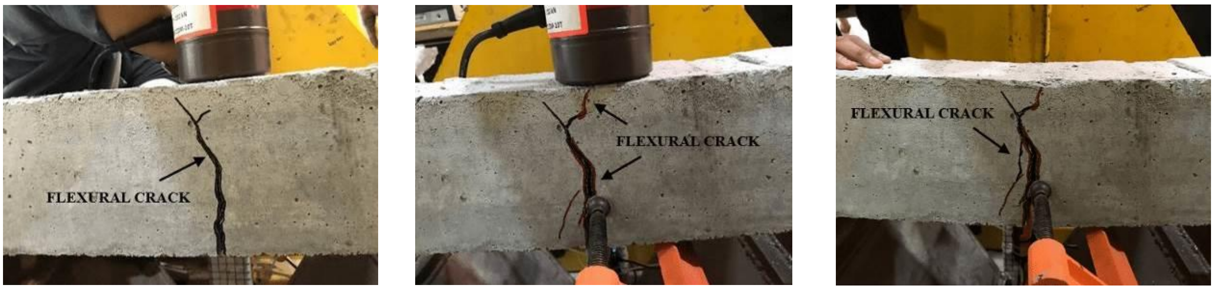


Fig. 14 *Final crack patterns with 10% spent garnet replacing sand*



(a) First impact **(b) Second impact** **(c) Third impact**

Fig. 15 *Crack patterns after first, second and third impacts on RC beam with 10% spent garnet replacing sand*

Flexural cracks appeared at the midspan of a reinforced concrete (RC) beam with 20% spent garnet replacing sand when subjected to a 100 kg load, as shown in Figure 16. These cracks worsened with repeated impacts, eventually leading to beam failure, as depicted in Figure 17(c). Interestingly, at 20% replacement, flexural cracks continue to be the predominant feature in the crack pattern. This suggests that the beam's behaviour aligns with conventional concrete mixes, even with a higher percentage of spent garnet replacement. Despite the increased garnet percentage, the beam's structural response remained largely unchanged, with flexural cracking prevailing in observed distress patterns.

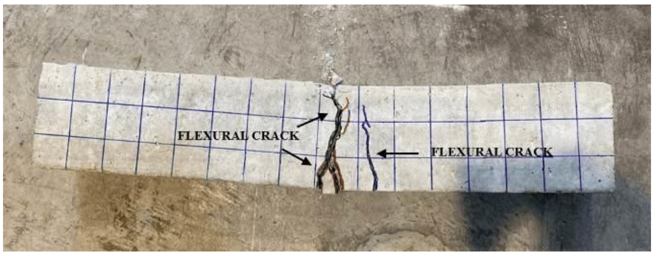


Fig. 16 *Final crack patterns with 20% spent garnet replacing sand*

(a) First impact **(b) Second impact** **(c) Third impact**

Fig. 17 *Crack patterns after first, second and third impacts on RC beam with 20% spent garnet replacing sand*

In Figure 18 shows the crack patterns indicating the beam's response to a 30% spent garnet replacement under impact load. Upon reaching a 30% replacement, there is a noticeable shift in crack patterns. Initially, flexural cracks occur during the first and second impacts, reflecting the influence of bending moments on the beam, as shown in Figure 19(a)(b). However, by the third impact in Figure 19(c), flexural-shear cracks emerge, indicating potential changes in the mix's mechanical properties. This shift may affect both flexural and shear resistance mechanisms within the beam.

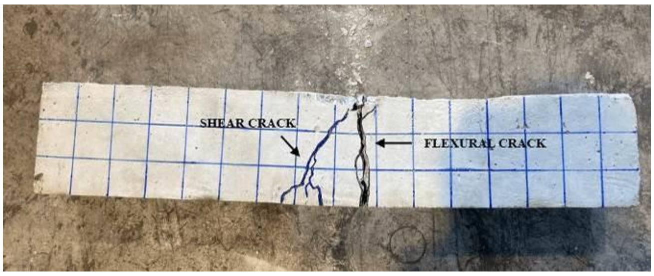


Fig. 18 *Final crack patterns with 30% spent garnet replacing sand*

(a) First impact **(b) Second impact** **(c) Third impact**

Fig. 19 *Crack patterns after first, second and third impacts on RC beam with 30% spent garnet replacing sand*

In Figure 20, a thorough analysis of crack patterns and damage progression revealed key findings. At a 40% replacement of spent garnet, noticeable changes in crack patterns emerge across the three impacts. Initially, flexural cracks arise during the first impact, indicating the onset of tensile stresses within the beam, as seen in Figure 21(a). However, flexural-shear cracks surface earlier, emerging during the second impact in Figure 21(b) and persisting into the third impact in Figure 21(c). This early appearance of flexural-shear cracking signifies a departure from typical behavior, suggesting that the increased garnet percentage significantly alters the beam's structural response, affecting both flexural and shear resistance mechanisms. Despite these alterations, the RC beam with 40% spent garnet replacement displays the least amount of damage and cracks among the specimens in Figure 20, indicating that a higher proportion of spent garnet enhances the structural integrity and resilience of reinforced concrete beams under impact loading conditions. This pattern suggests that RC beams with a higher percentage of spent garnet replacement are less prone to failure and damage.

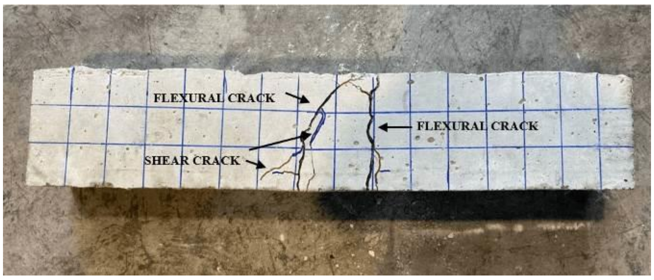
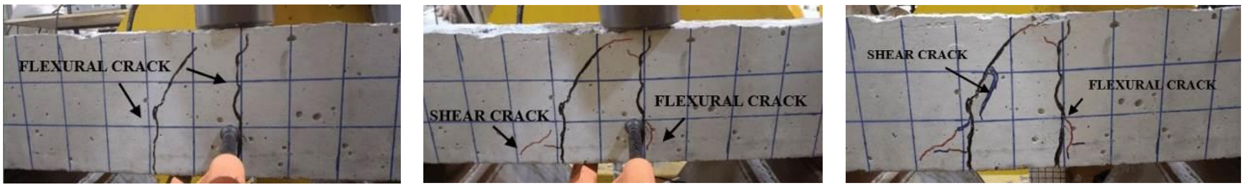


Fig. 20 *Final crack patterns with 40% spent garnet replacing sand*



(a) First impact **(b) Second impact** **(c) Third impact**

Fig. 21 *Crack patterns after first, second and third impacts on RC beam with 40% spent garnet replacing sand*

3.2.2 Crack Transition of RC Beam

Table 6 below reveals a trend in crack transition for the RC beam under repeated impact loads. Generally, the observed crack patterns become more complex with an increasing percentage of replaced garnet. Flexural cracks are present in 0%, 10% and 20% replacements, indicating strong strength. As the proportion of spent garnet increases, flexural-shear cracks emerge, signifying a change in the failure mechanism. This observation highlights the impact of spent garnet on the structural response of the RC beam to impact loading scenarios.

In simpler terms, adding garnet can strengthen the beam, but too much can cause different kinds of cracking. However, when 40% of the spent garnet is used, the beam sustains less damage compared to the control specimen. It is essential to strike the right balance between strength, cost, and environmental impact when deciding how much garnet to use in concrete mixes for different applications.

Table 6 *Crack transition of RC beam after first and second impact loads*

Percentage replacement of spent garnet	Crack pattern occurred on the beam		
	First impact	Second impact	Third impact
0%	Flexural cracks	Flexural cracks	Flexural cracks
10%	Flexural cracks	Flexural cracks	Flexural cracks
20%	Flexural cracks	Flexural cracks	Flexural cracks
30%	Flexural cracks	Flexural cracks	Flexural – shear cracks
40%	Flexural cracks	Flexural – shear cracks	Flexural – shear cracks

4. Conclusion

In conclusion, the investigation into the compressive strength of concrete with varying percentages of spent garnet as a replacement for sand revealed a consistent pattern. Lower replacement levels, such as 10%, exhibited a slight decrease in strength compared to the control concrete. However, as the replacement ratio increased to 20%, 30%, and 40%, there was a notable increase in compressive strength. The peak performance occurred at 40% spent garnet replacement, reaching 52.96 MPa at 28 days. This suggests that, within the parameters of this investigation, a greater proportion of replaced spent garnet enhances the concrete's compressive strength. This finding holds significant implications for concrete formulation and construction practices, suggesting that adding spent garnet, especially at higher replacement percentages, may be an effective method to increase the material's compressive strength. In addition to providing a useful purpose for wasted garnet, this discovery offers valuable guidelines for producing concrete mixtures with better mechanical properties, supporting more durable and environmentally friendly construction methods.

In analyzing the crack propagation of RC beams containing spent garnet under repeated low-impact loading conditions, the observations revealed distinct crack patterns. Initially, the control specimen shows flexural cracks during the first, second, and third impacts. This implies that the initial impact introduces flexural stresses leading to cracks. However, as the proportion of spent garnet increases, flexural-shear cracks emerge, suggesting an increase in strength but also a specific type of fracture. At 40% garnet inclusion, noticeable damage occurs, though less than in the control specimen. This hints that garnet addition, within limits, can enhance structural integrity and resilience. The reduced damage could be due to improved material properties or different structural response mechanisms caused by the presence of spent garnet. This underscores the importance of balancing cost-effectiveness, environmental impact, and strength improvement when choosing garnet amounts for concrete mixing in real-world applications.

Acknowledgement

The author extends sincere gratitude to the Faculty of Civil Engineering and Built Environment at Universiti Tun Hussein Onn Malaysia for their invaluable support and assistance throughout the duration of this project. Their unwavering encouragement and guidance have played a pivotal role in the successful completion of our work. Their expertise and collaborative efforts have significantly contributed to the overall accomplishment of our research objectives.

Conflict of Interest

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

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Basirun and Mokhatar; data collection: Basirun; analysis and interpretation of results: Basirun and Mokhatar; draft manuscript preparation: Basirun and Mokhatar. All authors reviewed the results and approved the final version of the manuscript.

References

Ab Kadir, M. A., Khiyon, M. I., Abdul, A. R., Kueh, A. B. H., Abdul Shukor Lim, N. H., Mohamad Ali Mastor, M. N., Zuhan, N., & Mohamed, R. N. (2019). Performance of spent garnet as a sand replacement in high-strength concrete exposed to high temperature. *Journal of Structural Fire Engineering*, *10*(4), 468–481. https://doi.org/10.1108/JSFE-10-2018-0025

Alaloul, W. S., Musarat, M. A., Rabbani, M. B. A., Iqbal, Q., Maqsoom, A., & Farooq, W. (2021). Construction Sector Contribution to Economic Stability: Malaysian GDP Distribution. *Sustainability*, *13*(9), 5012. https://doi.org/10.3390/su13095012

Ali, S. U., (2017). Development of Sustainable Concrete Using Iron Core Tailings as Sand Replacement. Phd Thesis, Universiti Teknologi Malaysia

Budiea, A. M. A., Azhar, N. N. M. N., Mokhatar, S. N., Muthusamy, K., & Satar, M. K. I. M. (2023). Properties of high strength concrete containing spent garnet as sand. *IOP Conference Series*, *1135*(1), 012048. https://doi.org/10.1088/1755-1315/1135/1/012048

Huseien, G. F., Sam, A. R. M., Huseien, G. F., Budiea, A., & Mirza, J. (2019a). Utilizing spend garnets as sand replacement in alkali-activated mortars containing fly ash and GBFS. *Construction and Building Materials*, *225*, 132–145. https://doi.org/10.1016/j.conbuildmat.2019.07.149

Jamaludin, N. F., Muthusamy, K., Isa, N. A., Jaafar, M. S., & Ghazali, N. (2021). Use of spent garnet in industry: A review. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2021.02.210

Jabatan Kerja Raya Malaysia (2014). *JRK 20800: Standard Specifications for Building Works*.

Kadir, M. a. A., Khiyon, M. I., Sam, A. R. M., Kueh, A. B. H., Lim, N. H. a. S., Mastor, M. N. M. A., Zuhan, N., & Mohamed, R. N. (2019). Performance of spent garnet as a sand replacement in high-strength concrete exposed to high temperature. *Journal of Structural Fire Engineering*, *10*(4), 468–481. https://doi.org/10.1108/jsfe-10-2018-0025

Khiyon, M. I. (2018). The Effects of Spent Garnet in High Strength Concrete Subjected to Elevated Temperature (Doctoral dissertation, Universiti Teknologi Malaysia)

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). https://doi.org/10.30880/ijie.2020.12.09.012

Li, H., Chen, W., & Hao, H. (2021). Analytical and numerical studies on impact force profile of RC beam under drop weight impact. *International Journal of Impact Engineering*, *147*, 103743. https://doi.org/10.1016/j.ijimpeng.2020.103743

Madjlessi, N., Cotsovos, D. M., & Moatamedi, M. (2021). Drop-weight testing of slender reinforced concrete beams. *Structural Concrete*, *22*(4), 2070–2088. https://doi.org/10.1002/suco.202000395

Omar, A., & Muthusamy, K. (2022). *Concrete Industry, Environment Issue, and Green Concrete: A Review*. *1*, 1–09. https://doi.org/10.15282/cons.v2i1.7188

Phang, Z. Q., Mokhatar, S. N., & Budiea, A. M. A. B. 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. http://publisher.uthm.edu.my/periodicals/index.php/rtcebe

Saviour, M. N. (2012). "Environmental impact of soil and sand mining: a review," International Journal of Science, Environment and Technology, vol. 1, no. 3, pp. 125-134, 2012

Thunga, K., & Das, T. V. (2020). An experimental investigation on concrete with replacement of treated sea sand as fine aggregate. *Materials Today: Proceedings*, *27*, 1017–1023. https://doi.org/10.1016/j.matpr.2020.01.356