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Impact Resistance of Sustainable Oil Palm Shell Light Weight Rubbercrete Reinforced with Wire Mesh

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Abstract

This paper investigates the impact performance of lightweight oil palm shells rubbercrete (OPSRC) slab reinforced with wire mesh against wire mesh spacing and slab thickness. Slabs of 300mm x 300mm size with various thickness were casted with 1 mm diameter wire mesh with varied spacing of 20 mm, 40 mm and 50 mm. The mix design for OPS: cement ratio of 0.2 with rubber crump: cement ratio of 0.1, 0.2 and 0.3. A drop-weight test rig impact with a steel ball weight of 1.25 kg was used in the research. A total of 36 samples were casted with a mortar grade of 28 N/mm^2. The mix design for OPS:cement (OPS:C) ratio of 0.2 with rubber crump: cement ratio of 0.1 produces best compressive strength of 28.1 N/mm2 for the lightweight requirement. A comparison between mesh spacing indicated that wire mesh 20 mm spacing for 40 mm thick slab produces better ultimate crack resistance performance by 3.97 times and 9.34 times than 40 mm and 50 mm spacing respectively and 10.66 times against the control sample without wire mesh. An energy absorption for 40mm slab with 20 mm spacing wire mesh produces better ultimate crack resistance performance by 4.99 times and 7.68 times than 40 mm and 50 mm spacing respectively and 8.20 times against the control sample without wire mesh. The 40 mm thick slab with a wire mesh spacing of 20 mm has a threshold values of 594 J and 228 N/mm^2 for an optimal performance in energy absorption and crack resistance, respectively. The use of OPSRC with wire mesh has increased its impact performance that can be utilized as a wall panel system partition.

Keywords: Impact resistance, Oil palm shell, Rubbercrumb

INTRODUCTION

The search of sustainable green materials for the construction industry has reached its critical time to mitigate the negative impact of the climatic change. It is critical to study the impact strength characteristics and assess its performance for eco-green construction materials for various potential use in the building industry. There is lack of research investigation been carried out on impact resistance of light weight reinforced concrete. Lightweight concrete is defined as concrete which is made from lightweight aggregates. Ragavendra and Sivakumar have studied the use of light weight plastic aggregate (LWPA) to reduce the use of conventional aggregate to produce a lightweight concrete [1]. The use of oil palm shell (OPS) to replace coarse aggregate been studied by Mannan and Ganapathy and their results showed that the concrete has a bulk density of 1,850 kg/m3 which met lightweight concrete requirement. The OPS concrete also able to reach compressive strength of 20-24 MPa (28 days) which met the strength requirement for lightweight concrete [2].

Impact resistance represents the ability of concrete to withstand repeated blows and absorb energy without adverse effect to cracking and spalling. Impact scenario can also be classified into low velocity impact and high velocity impact. A repeated impact test, a weighted pendulum Charpy-type impact test, a projectile impact test, and explosion-impact test, a constant strain rate test, a split Hopkinson bar test, and an instrumented pendulum impact test could be used to measure the impact resistance of fiber reinforced composites [3]. The impact resistance of material also can be measured by using the criteria such as the energy of fracture of the specimen, repeated impact tests, and the velocity and the size of the spall the specimen subjected to a blast loading surface [4]. However, the drop weight impact test which is recommended by the ACI Committee 544 [5, 6] is the simplest method.

The review paper on impact resistance on concrete target has been published by Zakaria Che Muda et al [7]. Impact resistance of oil palm shells lightweight concrete slab with bamboo fibers has been studied by Zakaria Che Muda et al. The results indicate that 2% volume fraction of bamboo fibers has an optimal performance for first crack resistance and ultimate crack resistance [8].

Researchers have investigated the presence of rubber crumb as an aggregate replacement has increased the strain capacity and the flexural toughness whilst reduces its flexural strength and Young's modulus [9]. The study from Osama et al. shows that the ductility increases when fine aggregate (sand) is replaced with rubber crumb. The higher ductility makes it promising for its use in seismic loading conditions. The crumb rubber decreased the compressive strength which was in this case being countered by using fibre reinforcement, which showed pleasant results [10]. The investigation by experiment on the strength and toughness properties of rubberized concrete mixtures has been conducted. The results indicate that there is about an 85% and 65% reduction in compressive strength when the coarse and fine aggregate was fully replaced by rubber and fine crumb rubber, respectively. However, the results indicate that using recycled rubber in Portland cement concrete mixtures increases the fracture toughness [11]. Energy absorbing capacity of the rubber crumb concrete was increased when rubber contents were below 10% and decreased when rubber contents more than 10% [12].

The objective of the paper is to study the behaviour of the impact energy and its impact resistance in terms of service (first crack) and ultimate (failure crack) impact resistance of lightweight rubbercrete slab against the thickness and the spacing of its wire-mesh reinforcement.

EXPERIMENTAL STUDY OF IMPACT PERFORMANCE OF WIRE MESH REINFORCED OPSRC

Materials properties and mix proportions

Ordinary portland cement (OPC) – Type 1 which is used in the reported study has been tested for various proportions as per ASTM C150. The specific gravity of cement was 3.15 and the Blaine fineness was 2.910 cm^3/g. The river sand with maximum size of 2.36 mm and a modulus of fineness of 3 was used as fine aggregate. The specific gravity was 2.6 and the absorption value was 6.0%. The aggregate gradation of oil palm shell (OPS) seized less than 14 mm was carried out to ensure the quality of mix design. The water-to-cement (w/c) ratio is fixed and equal to 0.4, the cement content is 530 kg/m^3, the superplasticizer is 2% of the weight of cement content, the sand:cement ratio is 1.75 and the OPS-to-cement (OPS:C) ratio of 0.2 was selected for this study. The rubber crump was obtained by crushing old waste tires by a granulator to a size of 5-7 mm diameter. The rubber crump has to be free of steel and fibre which are also parts of the tires. The wire mesh used in this research for reinforcement with spacing of 20 mm, 40 mm and 50 mm. The materials were shown in Figure 1.

Oil palm shell (OPS) | Rubber crump (RC) | Wire mesh (WM)

Figure 1. Oil palm shell, rubber crump, and wire mesh for slab reinforcement

Preparation and testing of specimens

The oil palm shell (OPS) which is obtained from a Palm Oil factory or mill is cleaned to remove the dirt, dust as well as the leftovers of the oil and dried at room temperature. The absorption capacity of OPS caused the surface to be saturated during mixing and lead to a reduction in workability. Therefore, the OPS need to be presoaked before concrete mixing and the wire mesh was cut into 300 x 300 mm specimen size. The formwork for the concrete slab was made using plywood and designed to be reattach able for further use. Grease was applied on the formwork before casting the concrete mix to easy the detachment of the concrete slab after hardening. The slump and compaction factor tests were done to measure workability of the fresh concrete. The casting of the slab concrete can be done after all materials well prepared and met the workability requirement. The concrete was poured into the formwork up to half of slab thickness and next was placing of wire mesh. Then the second layer of the concrete mix was laid on top of the wire mesh to cover the wire mesh. The OPSRC slab was casting for 24 hours and then cured in water bath to the day of testing. The concrete slab was cured for 28 days and then removed for testing purpose. A layer of whitewash is applied on the bottom of the specimen surface to ease in crack observation process during impact testing.

Table 1. Mixing proportions of OPSRC

Specimens	Materials (kg/m^3)					
	Cement	Water	Sand	OPS	Superplasticizer	Rubber crump
NC	530	212	930	108	11.13	0
OPSRC-0.1	530	212	930	108	11.13	54
OPSRC-0.2	530	212	930	108	11.13	108
OPSRC-0.3	530	212	930	108	11.13	162

Note:

NC represents normal concrete without rubber crump

OPSRC represents oil palm shell rubber crump in OPSRC-n "n" represent rubber crump content

EXPERIMENT METHODOLOGY AND DATA ANALYSIS

A fabricated tests rig consisting of two components: the steel rack with steel channel to allow the drop weight to roll from it and the table to hold and support the slab specimens. The test specimen will be put into the slot on the supports. The test specimen and the support were put besides the steel rack. A 1.25 kg steel ball (drop-weight projectile) which is slipped from the steel channel at a various height of 155 mm for slab thickness of 20 mm and 300 mm for slab thickness of 30 mm and 40 mm to centre of slab to produce impact loading. The steel ball will be released and allowed to free fall onto the slab specimen after both the slab specimen and the drop weight are in position. The test set-up are as shown in Figure 2.

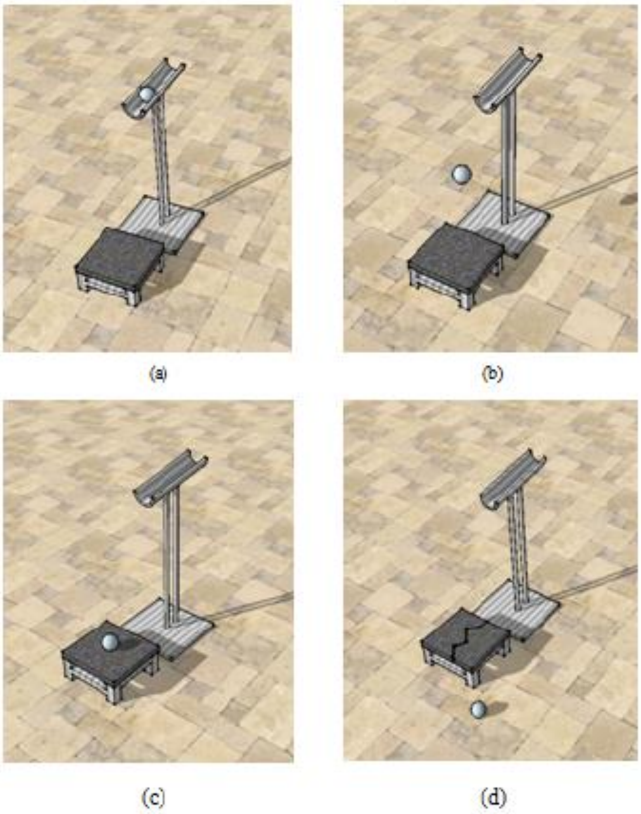


Figure 2. Drop weight impact test set-up

The first crack and the ultimate crack were observed and the number of blows to produce the crack was recorded. Upon the ultimate failure, the total crack length, the crack width, and the crack depth are recorded. Kankam [13] proposed equation to calculate the ultimate crack resistance R_u as follows:

$$R_u = \frac{Ne}{l_c d_c w_c}$$

where N is number of blows; e is energy per blow (J); l_c is total length of all cracks; d_c is maximum crack depth; and w_c is maximum crack width. The crack length and width are measured using meter and ruler, while the maximum crack depth is assumed to be 15 mm for all the specimens.

The crack resistance ratio C_r can be calculated using:

$$C_r = \frac{R_u}{f_{cu}}$$

Where C_r is impact crack resistance ratio and f_{cu} is cube compressive strength of concrete in MPa.

RESULTS AND DISCUSSION

Effect of rubber crump content on compressive strength and density of OPSRC

Concrete cube size of 100 x 100 x 100 mm^3 was casted and tested to get density and compressive strength of OPSRC. Figure 3 shows that density for normal OPRSC is higher than 20 kN/m^3. The inclusion of rubber crump has reduced the density of concrete by 5.7%, 12.9%, and 15.5 %, for 0.1, 0.2, and 0.3 rubber crumb to cement ratio, respectively. It can be observed that the higher RC:C ratio the lower density and of concrete. The OPSRC with RC: C ratio of 0.1 produced concrete with density of 20 kN/m^3. It is considered suitable to be used for lightweight concrete.

The inclusion of rubber crump has reduced the compressive strength of concrete as well by 1.0%, 38.8%, and 72.7 %, for 0.1, 0.2, and 0.3 rubber crumb to cement ratio, respectively. The higher the RC:C ratio the lower compressive strength of concrete. However the compressive strength of OPSRC with rubber crump to cement ratio of 0.1 was selected to be used for construction of concrete slab since the density is 20 kN/m^3 and the compressive strength more than 25 N/mm^2.

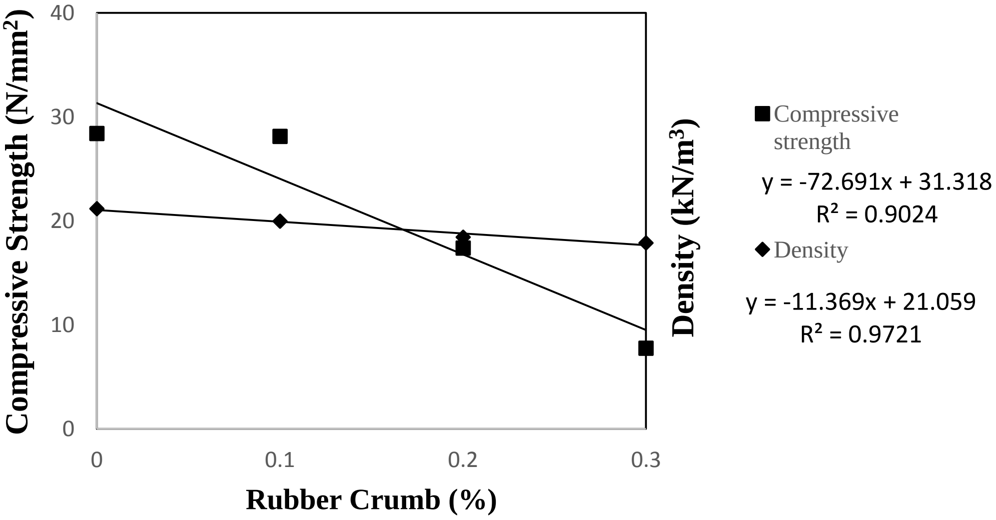


Figure 3. Compressive strength and density of OPSRC

Effect of slab thickness on energy absorption

The impact energy absorbed by the concrete slabs was obtained by multiplying the energy per blow by the number of blows for both the first and the ultimate crack failure. Impact energy absorption for both service and ultimate loads are given in Figure 4 and 5. From the figures can be observed that the thickness of the slab has a direct impact on the crack resistance it is directly proportional to the impact energy absorption. This means that the thicker the slab is the higher the impact energy absorption for both the service and ultimate loading. The graphs show clearly that the thickness of the slab has an great effect on the impact energy absorption for both service and ultimate load no matter if the slab is reinforced with wire mesh or not. Figure 4 shows the maximum energy absorption for first crack without wire mesh (control slab) are 4.43 J, 22 J, and 67.44 J, respectively. The energy absorption for service load for 30 mm and 40 mm slab thickness increased 5 and 15 times, respectively compared to 20 mm slab thickness.

Figure 5 shows the maximum energy absorption for ultimate crack without wire mesh (control slab) are 6.33 J, 25.75 J, and 72.34 J, respectively. The energy absorption for service load for 30 mm and 40 mm slab thickness increased 4 and 11 times, respectively compared to 20 mm slab thickness.

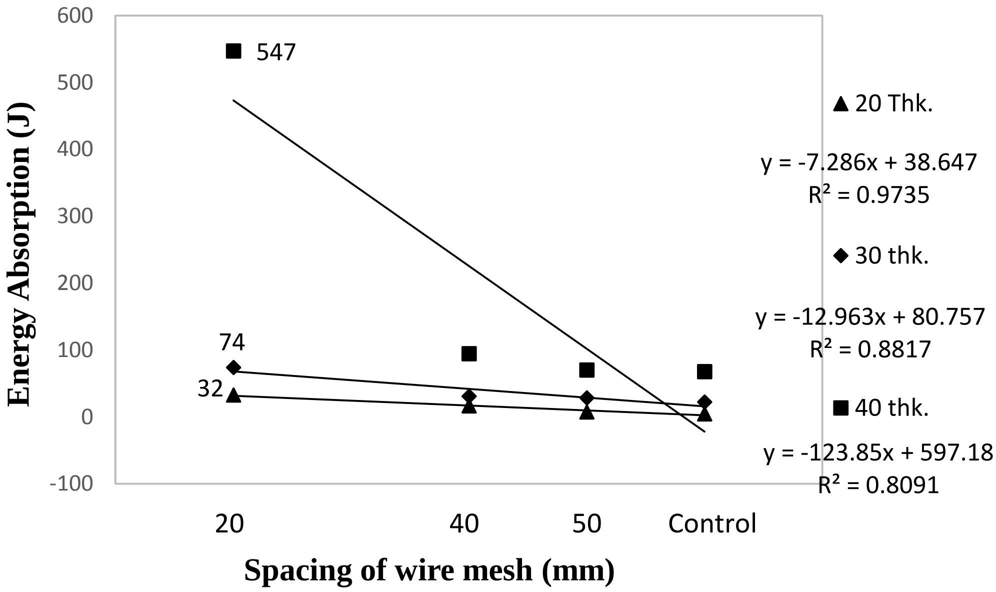


Figure 4. Energy absorption for service load

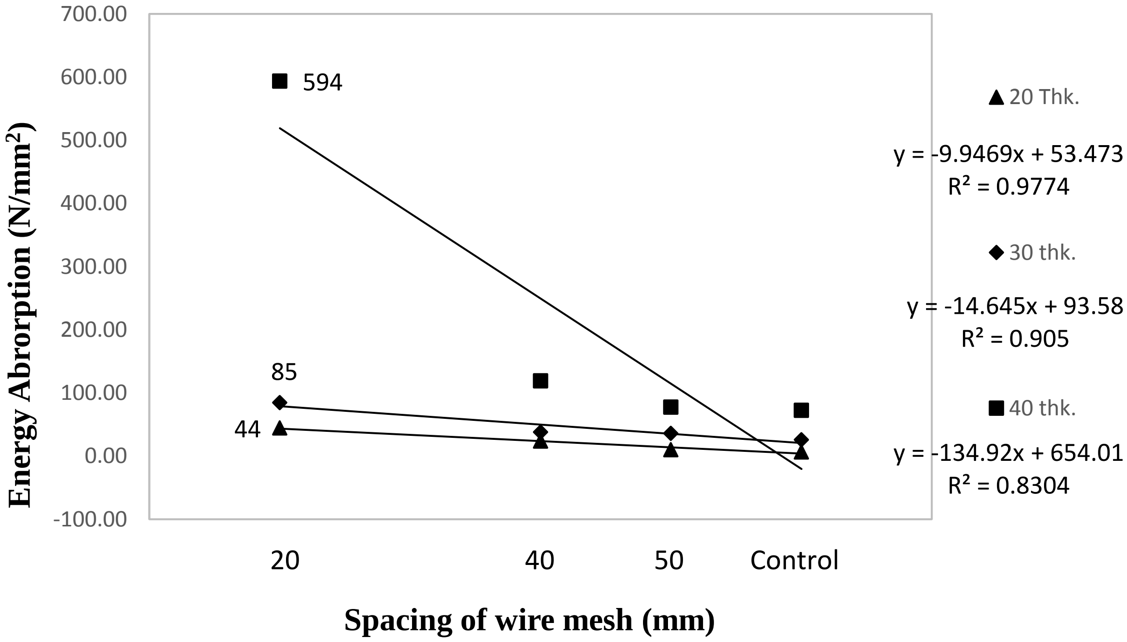


Figure 5. Energy absorption for ultimate load

Effect of wire mesh spacing on energy absorption

The OPSRC without wire mesh given less contribution to the impact energy absorption as shown in Figure 4 and 5. Comparing, the maximum energy absorption for service load for various wire mesh spacing, the slab with wire mesh spacing of 20 mm show the best performance in absorbing of impact loads. For slab thickness of 40 mm with wire mesh 20 mm, 40 mm, and 50 mm spacing produce energy absorption of 547 J, 94 J, and 69.8 J, respectively. For slab thickness of 40 mm without wire mesh produce energy absorption of 67.4 J only. It can be concluded that the present of wire mesh increased impact energy absorption of slab by 8, 1.4, and 1.04 times for first crack.

Figure 5 shows the energy absorption for ultimate load for various wire mesh spacing. The slab with wire mesh spacing of 20 mm show the best performance in absorbing of impact loads for ultimate load as well. For slab thickness of 40 mm with wire mesh 20 mm, 40 mm, and 50 mm spacing produce energy absorption of 549 J, 119 J, and 77.25 J, respectively. For slab thickness of 40 mm without wire mesh produce energy absorption of 72.34 J only. It can be concluded that the present of wire mesh increased impact energy absorption of slab by 7.6, 1.6, and 1.07 times for ultimate crack.

The slab with thickness of 40 mm absorbed potential energy for service load 16.7 times and 2.3 times than 30 mm and 20 mm thickness, respectively. The slab with thickness of 40 mm also absorbed potential energy for ultimate load 13.4 times and 1.9 times than 30 mm and 20 mm thickness, respectively.

The maximum energy absorption for service load without wire mesh (control slab) and with wire mesh 20 mm spacing for 40 mm thick slab are 67 J and 547 J, respectively. The difference of energy absorption between them is 87.6 %. Comparing the maximum energy absorption for first and ultimate crack is 547 J and 594 J with difference of 7.8 % only, the wire mesh given less contribution to energy absorption during ultimate limit. Comparing the energy absorbed during the first and ultimate crack for specimen with and without wire mesh, the wire mesh contributes more to the early energy absorption; it helped improve the energy absorption during the first crack. That means that the wire mesh absorbed more energy until the crack started to widen and propagate further and lose its bonding, which then lead to failure. Once the crack appears on the slab, the slab capacity to absorb the impact energy will be reduced drastically.

Effect of slab thickness on crack resistance of OPSRC

The thickness of the slab has a direct impact on the crack resistance it is directly proportional to the crack resistance. This means that the thicker the slab is the higher the first and ultimate crack resistance. Figure 6 and 7 show clearly that the thickness of the slab has an impact on the service and ultimate failure crack no matter if the slab is reinforced with wire mesh or not. Figure 6 shows the first crack resistance without wire mesh (control slab) are 7.04 N/mm^2, 15.71 N/mm^2, and 19.83 N/mm^2, respectively. The first crack resistance for 30 mm and 40 mm slab thickness increased 2.2 and 3 times, respectively compared to 20 mm slab thickness.

Figure 6 shows the ultimate crack resistance without wire mesh (control slab) are 10.28 N/mm2, 18.34 N/mm2, and 21.3 N/mm2, respectively. The ultimate crack resistance for 30 mm and 40 mm slab thickness increased 1.8 and 2.1 times, respectively compared to 20 mm slab thickness.

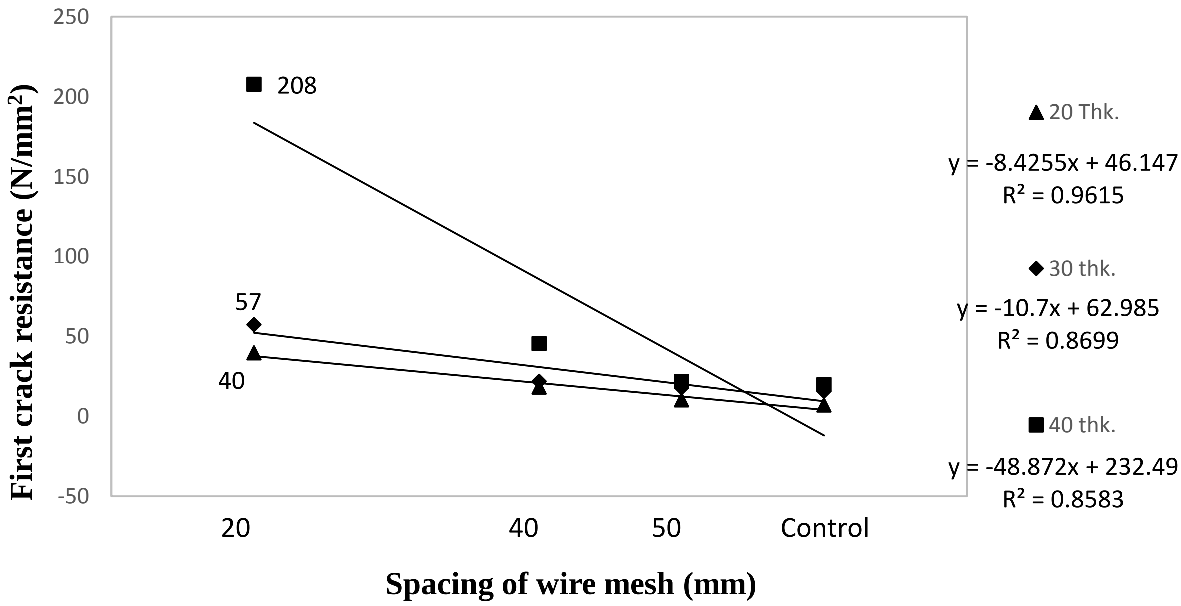


Figure 6. First crack resistance for various wire mesh spacing and slab thicknesses crack resistance of slab by 10.7, 2.7, and 1.15 times compared to slab without wire mesh.

Effect of wire mesh spacing on crack resistance of OPSRC

The OPSRC without wire mesh did not contribute much to the crack resistance as shown in Figure 6 and 7. Comparing the first and ultimate crack resistance for various wire mesh spacing, the slab with wire mesh spacing of 20 mm show the best performance in resisting of impact loads. For slab thickness of 40 mm with wire mesh 20 mm, 40 mm, and 50 mm spacing produce first crack resistance of 208 N/mm2, 45.46 N/mm2, and 21.67 N/mm2, respectively. For slab thickness of 40 mm without wire mesh show crack resistance of 19.83 N/mm2 only. It can be concluded that the present of wire mesh increased first crack resistance of slab by 10.5, 2.3, and 1.1 times compared to slab without wire mesh.

Figure 7 shows the ultimate crack resistance for various wire mesh spacing. The slab with wire mesh spacing of 20 mm show the best performance in resisting impact load for service and ultimate loading. For slab thickness of 40 mm with wire mesh 20 mm, 40 mm, and 50 mm spacing show ultimate crack resistance of 228 N/mm2, 57.3 N/mm2, and 24.4 N/mm2, respectively. For slab thickness of 40 mm without wire mesh show ultimate crack resistance of 21.3 N/mm2 only. It can be concluded that the present of wire mesh increased the ultimate crack resistance of slab by 10.7, 2.7, and 1.15 times compared to slab without wire mesh.

From Figure 6 and 7 can be observed that the crack resistance show similar pattern. The crack resistance of the specimens increased as the spacing of wire mesh decreased. Comparing the first crack and ultimate crack resistance for specimen with and without wire mesh, the wire mesh contributes more to the first crack resistance. Therefore it helped improve first crack resistance during the first crack. That means that the wire mesh resisted a lot of energy until the crack started to widen and propagate further and lose its bonding, which then lead to failure. Once the crack appears on the slab, the slab capacity to resist the impact energy will be reduced drastically.

Furthermore, the addition of wire mesh also proved that it resisted a much larger impact resistance. It can be observed that the smaller wire mesh spacing and the thicker specimens, the higher the impact energy absorption for both first and ultimate crack. As the wire mesh was place in the middle of the specimens, it contributed for in plane stiffness and prevented the concrete failing and deforming easily.

Effect of slab thickness and wire mesh spacing on crack resistance ratio of OPSRC

Figure 8 shows slab thickness and wire mesh spacing effect on crack resistance ratio (Cr). It can be observed that increasing the thickness is directly proportional to the crack resistance ratio. The maximum crack resistance ratio for, 20 mm thickness, 30 mm thickness and 40 mm thickness is 1.93, 2.39 and 8.1, respectively. It also can be observed that decreasing the spacing is indirectly proportional to the crack resistance ratio. The maximum crack resistance ratio for the control sample, 50mm spacing, 40mm spacing and 20mm spacing is 0.76, 0.87, 2.04 and 8.1, respectively.

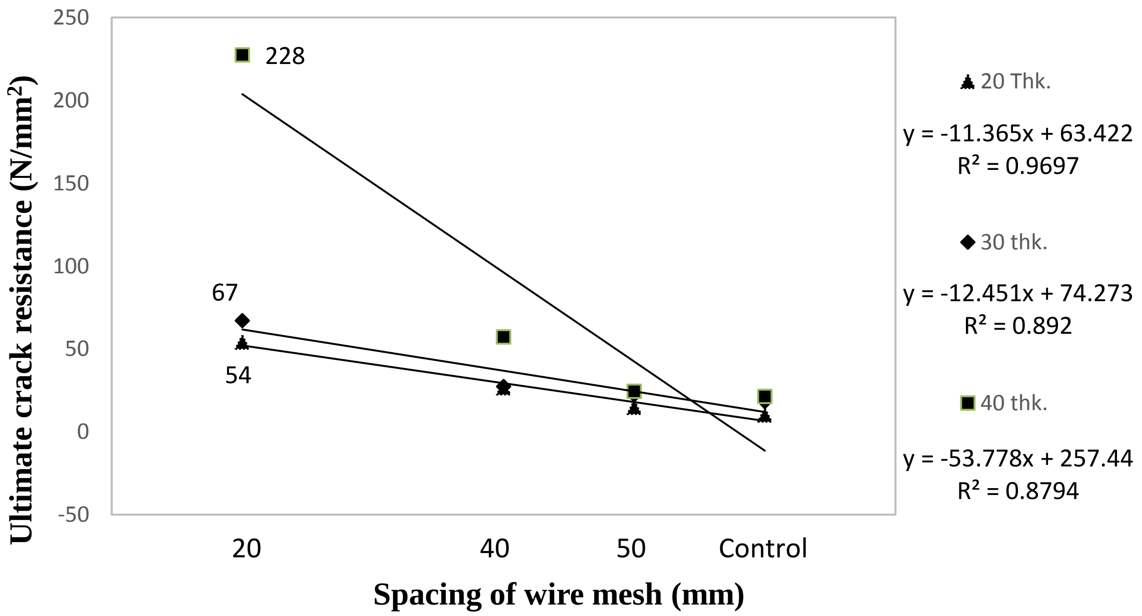


Figure 7. Ultimate crack resistance for various wire mesh spacing and slab thicknesses

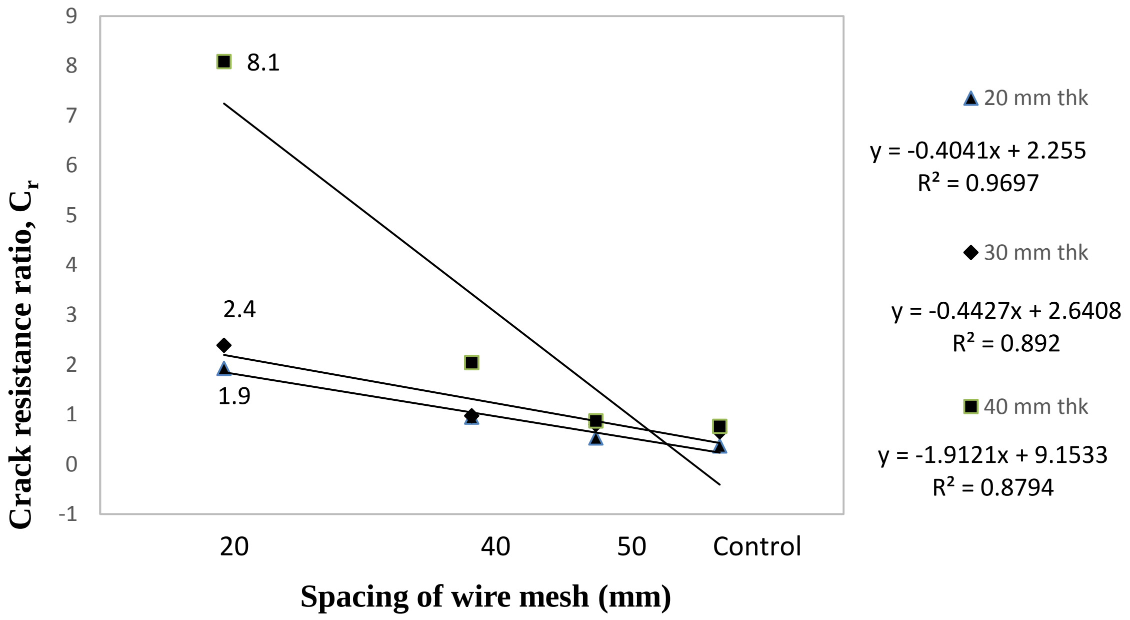
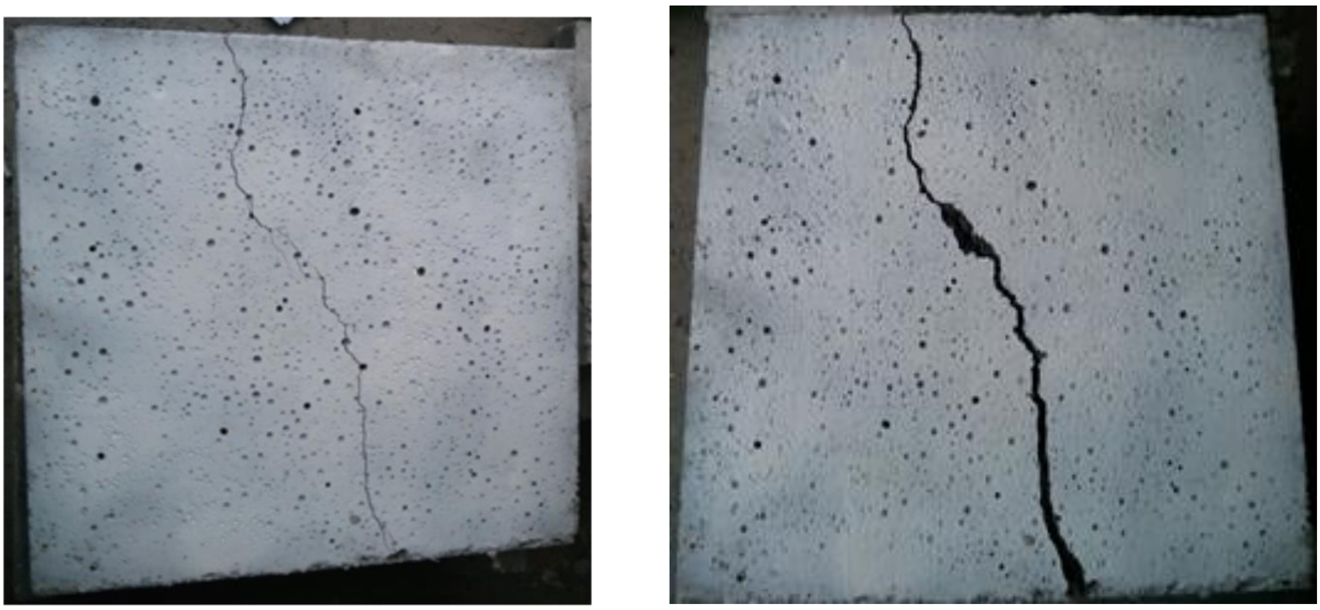


Figure 8. Crack resistance ratio for various wire mesh spacing and slab thicknesses

Failure Pattern of OPSRC

There are two types of failure mode based on the experimental observations. For specimens without wire mesh (control specimen) broke into two pieces at failure. The first crack developed along the middle of the specimens during the initial impact loading. The specimens are freely supported only at two sides, hence the impact energy only able to travel through the supported sides. Moreover the stress induced at the unsupported sides leads to crack development.

Figure 9(a) shows the first crack development on control specimen (40 mm slab thickness) under impact loading. The crack width is very fine (hair line crack) for the first crack. The crack developed in one direction only which is the least supported side. All the control specimens show a similar pattern with different crack length.



(a) (b)

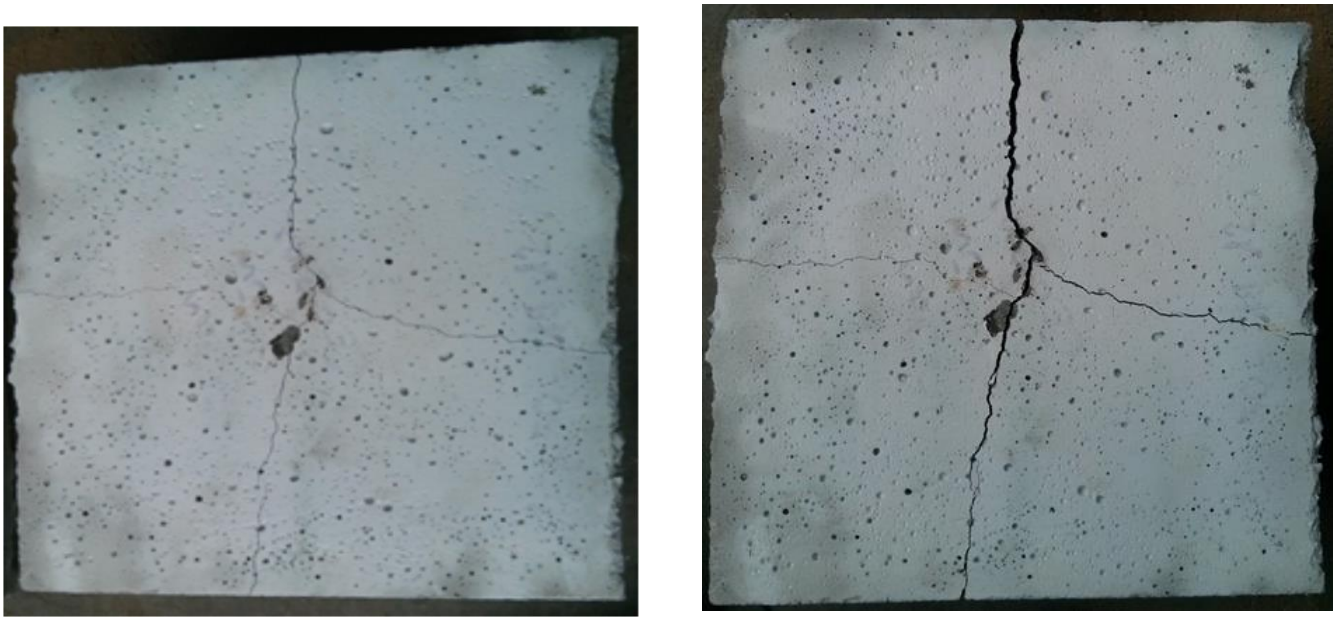
Figure 9. Failure Pattern of first (a) and ultimate failure crack (b) for 40mm thick slab without wire mesh reinforcement

Figure 9(b) shows the failure crack of control specimen (40 mm slab thickness) where it was separated into two pieces. During the experimental process, after first crack developed, the specimen started to deflect under impact loading. After one or two blows, the specimens fail ultimately without reinforcement. It means that the control specimen is unable to sustain more impact loading and hence fail in short period.

Furthermore, the specimens were reinforced with a wire mesh, the failure mode was totally different from the first failure mode as mentioned previously, where the specimens broke into two pieces at ultimate failure. Figure 10(a) shows the first crack development on specimen (40 mm thickness) reinforced with wire mesh. The crack development was seen in a two directional pattern. It means that the wire mesh distributed the impact energy throughout the concrete surface instead of only one direction, where the impact energy was shared for both directions with lesser magnitude. Additionally the wire mesh contributes in crack development control, where the impact energy tends to travel through it instead of a random direction, causing development of the crack along the direction of reinforcement.

A comparison between Figs 9(a) and 10(a) shows that the crack development on specimens without wire mesh is not as straight as the crack developed on specimens reinforced with a wire mesh. Specimens which were reinforced a wire mesh provide better crack control and higher impact resistance with respect to first crack development. Also, the number of blows required to achieve ultimate failure increase by 500% as compared to specimens without wire mesh reinforcement. Between the loading periods from the first crack to ultimate failure, some of the concrete already detached from the specimens, especially at the area under the impact loading area.

Figure 10(b) shows the crack pattern of slab 40 mm thickness with 20 mm wire mesh at the ultimate failure. The additional cracks was developing and branching out from the first crack. Unlike the specimen without wire mesh reinforcement, specimens reinforced with wire mesh were bonded altogether. It can be observed that the presence of wire mesh improved the crack control. Addition of a wire mesh improved the impact resistance of specimen significantly especially for wire mesh 20 mm. The wire mesh was placed inside the specimens at the middle height of specimens without anchorage; it means that the wire mesh did not have any supports to transfer the impact loading. Therefore it can be concluded that the ultimate failure of specimen was caused by the low impact resistance of concrete itself but not because of the wire mesh failure. As the impact loading continued, the concrete tend to lose bonding and spall off, exposing the wire mesh. However the wire mesh was still intact and had not failed. It was assumed that the specimens were over reinforced as the wire mesh had overall better impact resistance performance.



(a) (b)

Figure 10. Failure Pattern of (a) first and (b) ultimate failure crack for 40mm thick slab with 20 mm spacing wire mesh

CONCLUSION

The following conclusions can be derived from the experimental results;

- Mix design with RC:C ratio of 0.1 produces the best compressive strength of 28 N/mm^2, more than minimum requirement of 25 N/mm^2 for concrete structure.
- The thickest slab with the smallest spacing has the highest energy absorption, first and ultimate crack resistance as well as crack resistance ratio. 40 mm thick slab with a wire mesh spacing of 20 mm has a threshold values for an optimal performance in energy absorption and crack resistance.
- Maximum threshold energy absorption for first and ultimate failure for slab 40 mm thickness with 20 mm wire mesh spacing are 547 J and 594 J, respectively. An energy absorption for 40mm slab with 20 mm spacing wire mesh produces better ultimate crack resistance performance by 4.99 times and 7.68 times than 40 mm and 50 mm spacing respectively and 8.20 times against the control sample without wire mesh.
- Maximum threshold crack resistance for first and ultimate failure as well as crack resistance ratio for slab 40 mm thickness with 20 mm wire mesh spacing are 208 N/mm^2, 228 N/mm^2 and 8.1 N/mm^2 respectively. A comparison between mesh spacing indicated that wire mesh 20 mm spacing for 40 mm thick slab produces better ultimate crack resistance performance by 3.97 times and 9.34 times than 40 mm and 50 mm spacing respectively and 10.66 times against the control sample without wire mesh.
- The crack development on specimens without wire mesh is not as straight as the crack developed on specimens reinforced with a wire mesh. Specimens without wire mesh show one direction crack development, while specimens with wire mesh show two directions. The closer the spacing of the wire mesh with its optimum thickness have better crack control and its ability to break into many segmental sections in its failure mode. Wire mesh reinforcement effect can be seen after crack failure, the specimen still bonded together since the wire mesh still hold the concrete even after crack failure.

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