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EXPERIMENTAL STUDY ON HYBRID REINFORCED CONCRETE SLABS SUBJECTED TO IMPACT LOADING

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ABSTRACT
The aim of this study was to examine the concentration of total phenols and antioxidant capacity of flower honey The use of hybrid-fibers (i.e. fibers having steel and plastic fibers in varying proportions) in the preparation of concrete mix could be an effective strategy for improving impact resistance of concrete slabs. However, there is little research on the behavior of concrete slabs containing hybrid fibers under low velocity impact loads. A rigorous experimental program was used to investigate the effectiveness of hybrid-fibers on the impact behavior of eight concrete slabs in this study. The slabs were all 1700* 1700* 100 mm in size and included varying amounts of Steel and Polypropylene fibers. The free-fall impact tests were conducted with a 200-kilogram hammer and two different drop heights (1m and 2m). The relationships between impact loads, displacements, and stresses were recorded. The dynamic responses gained during tests, as well as the failure modes detected. The test findings show that, when appropriately built, hybrid-fiber reinforcement can greatly improve the overall impact resistance of concrete slabs, stop crack growth, and thereby reduce the size of the damaged area. Under impact force, the specimen M3 with a mix of 1% steel fibers and 0.5% PP fibers performed the best.

KEYWORDS: hybrid fiber reinforced concrete; impact resistance; free falling impact load; low velocity impact load.

1. INTRODUCTION
For the building projects, structural impact issues have become increasingly essential. Accidental loads like as fallen objects, collisions, explosions, aircraft crashes, and fragment penetration are all taken into account while designing reinforced concrete (RC) strategic structures. Some of these incidental loads are also relevant in the construction of protective structures, which are primarily made of RC in the process industry or fortification installations for defense (Abadel at. al., 2012).
Othman and Marzouk [2016] assessed that Low velocities high mass impact loading scenarios with velocities up to 10 m/s was the most common impact situations for civil engineering. Many ancient structures are increasingly vulnerable to sudden loads, demanding extra vigilance and engineering solutions to assure their stability and impact resistance. Low-velocity impact situations include transportation infrastructure vulnerable to vehicle collisions, airport runway platforms during aircraft landings, and offshore structures prone to ice and/or ship contact and explosions. Dynamic loads induced by natural disasters such as tornadoes and earthquakes are similarly associated to low-velocity impact. As a result, structures made of reinforced concrete must be developed to withstand these forces.

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The use of fibers in the preparation of concrete mix could be an effective and efficient way for improving the impact resistance and ductility of normal strength concrete slabs. The idea of combining the effectiveness of multiple types of fibers has recently been researched, and novel materials known as hybrid fiber reinforced concretes (HFRC) have been developed by combining fibers of varied geometry and/or substance (Banthia and Nandakumar, 2003). Although there is very little study on the use of hybrid fibers to improve concrete impact qualities, there is a lot of research on enhancing concrete impact behavior using a single type of fiber (Feng et al., 2018).
The study on impact behavior of HFRC structures is still restricted, as shown by the preceding survey of literature, and the corpus of research work is insufficient to provide a definitive definition of the structural behavior of FRC structures under impact. The purpose of this study was to investigate the local damage behavior of hybrid reinforced concrete slabs (by using steel fiber and PP fiber) when subjected to an impact load.

2. LITERATURE REVIEW

Fiber reinforcement is widely employed to provide brittle cementitious matrixes more toughness and ductility. The impact strength of normal concrete can be boosted by 2–15 times depending on the amount of steel fibers employed (Schrader, 1981).

Mo et al., [2021], used a drop hammer to test the plain and fiber reinforced oil palm shell concrete (FROPSC) panels for impacts. Different proportions of polypropylene (0.1 percent, 0.25 percent, 1%) and steel (0.75 percent, 0.9 percent, 1%) fibers with uncrushed and crushed oil palm shells were investigated (OPS). They found that FROPSC specimens with uncrushed OPS exhibit greater impact resistance than those with crushed OPS.

Khin et al., [2013], investigated the impact resistance of hybrid FRC. The fibers utilized were a mix of polyvinyl alcohol (PVA) and steel fibers (1.75 percent PVA fiber and 0.58 percent steel fiber). When compared to plain concrete and a hybrid-fiber reinforced reference specimen with 1.5 percent PVA and 0.5 percent steel fibers, this material showed enhanced impact resistance and energy absorption capability. However, the corpus of knowledge about hybrid-fiber concrete's high-velocity impact behavior is currently restricted, particularly in terms of structural performance under blast stress.

Through a rigorous experimental program, **Almusallam et al., [2021]**, investigated the usefulness of hybrid-fibers in improving the impact resistance of slabs. The hybrid-fibers in the concrete resulted in smaller crater volumes and less spalling and scabbing damage, according to the test results. The hybrid-gibers stop the fracture from spreading and thereby reduce the size of the affected region. They also estimated the penetration depth thickness by altering the NDRC equation's impact function to account for hybrid-fiber effects. It was also expected that the ballistic limit will be reached. The prediction of the ejected concrete mass from the specimens' front and back sides was then proposed using a simple formula.

Mousavi and Shafei [2019], attempted to use of hybrid FRP-steel rebar in the construction of impact-resistant RC slabs in order to reduce deflection and recover damages to structures that have been hit. Hybrid FRP-steel RC square slabs with a length of 1800mm and a depth of 130mm were doubly reinforced in both planar directions, with four layers of longitudinal hybrid FRP-steel reinforcing bars. Models are first validated using current experimental results before being extended for parametric research under impact loads using a nonlinear FEA algorithm. Material energy, maximum and residual deflection, load impulse, and maximum reaction force were all retrieved from the structural reactions. The hybrid FRP-steel rebars is capable of reducing induced damage in concrete and resulting deflection, according to the findings. Furthermore, while over-reinforcing results in minimal deflections, it should be avoided in hybrid FRP-steel reinforced slabs to improve energy absorption. Steel dissipates the imparted energy, while FRP material minimizes damage. This study innovation is defined as the use of hybrid FRP-steel fiber rebars to reduce excessive deflection of slabs during repeated impacts, which is critical for the structural integrity of such structures.

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Choudhary et al., [2021], focuses on the design of steel fiber reinforced concrete wall panels and evaluations of its performance characteristics under compression, flexural, and impact loads when compared to conventional concrete (CC) wall panels. Peak load vs. deflection was plotted, and the best peak load was found at 1.75 percent fiber content. In addition, the value of impact blows was determined to be higher for the larger concentration of fibers in the impact test.

Kheyroddin et al., [2021], investigated the impact resistance of concrete specimens using macro-synthetic steel fibers and bidirectional carbon fiber-reinforced polymers (CFRPs). Under impact stress, 54 concrete cylindrical specimens with varying compressive strengths and fiber content ratios were investigated. Weight (46.7 and 66.8 kg) was dropped from a height of 1.62 m on the specimens. The use of steel fibers or CFRP wrapping, respectively, enhanced the impact resistance of the concrete specimens (equivalent to the number of weight drops).

According to Lee et al., [2020], it is still unclear how to quantify structural member impact resistance because it is difficult to compare test data gathered from multiple impact tests done under different test conditions. Due to the difficulty in collecting force-displacement curves, the majority of the studies presented measured force-time and displacement-time relations rather than force-displacement relations.

3. MATERIALS AND METHODS

In the present detailed experimental program, a total of eight hybrid-fiber reinforced concrete slabs were casted. The target compressive strength is 30 MPa.

Test specimens

All the slab specimens had a size of 1700*1700*100 mm and were prepared using different proportions of steel and ECONO-MONO polypropylene (PP) fibers as shown in Table 1, were used in the preparation of the hybrid-fibers. Two crimped steel fiber types are used with the Young's modulus of 210 GPa: **3Dramix** with a length of 35 mm, diameter of 0.55 mm and tensile strength of 1345 MPa and **5Dramix** with a length of 60 mm, diameter of 0.9 mm and tensile strength of 2300 MPa. ECONO-MONO Polypropylene fibers with length 19 mm and tensile strength of 660 MPa was used. These values of the fibers are manufacturers reported values.

It had been targeted for experiments that the concrete compressive strength of RC slabs should be 30 MPa. The concrete mix ratio prepared for that purpose has been presented in Table 1.

The slabs have the following names:

1-C1 - Control Specimen,
2-M1 - 65/35 3D,
3-M2 - 65/35 3D + PP,
4-M3 - 65/35 3D high ratio + PP,
5-M4 - 65/60 5D,
6-M5 - 65/60 5D + PP,
7-M6 - 65/60 5D high ratio + PP,
8-M7 – PP

Table 1 Mix proportion values (for 1 m3)

Specimen	Cement (kg)	Water (kg)	Course Aggregate (kg)	Fine Aggregate (kg)	65/35 3D Steel Fiber (kg)	65/60 5D Steel Fiber (kg)	PP (kg)	Fiber Volume (%)		
								Steel Fiber		PP
								65/35 3D	65/60 5D	
C1	1138.66	534.65	2866.88	2320.67	0	0	0	0	0	0
M1					225.42	0	0	1	0	0
M2					112.71	0	18.785	0.5	0	0.5

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M3					225.42	0	18.785	1	0	0.5
M4					0	225.42	0	0	1	0
M5					0	112.71	18.785	0	0.5	0.5
M6					0	225.42	18.785	0	1	0.5
M7					0	0	37.57	0	0	1

Impact load test

An impact test was carried out using a drop weight test machine with a maximum capacity of 3.924 kJ. A single impact load was applied to the mid-span of the slab specimens by dropping a free-falling 200 kg drop weight from 2 drop heights of 1.0 and 2.0 m. The weight of the steel hammer was constant in the test.

Test setup and Instrumentations

The drop-weight test setup has commonly used for impact experiments and there are many studies where impact load is applied to slab, beam and column structural elements via this setup. In the scope of this study, a novel moveable drop-weight test setup has been used to apply the impact load. The designed drop-weight test setup allows for dropping steel hammer from a height which is up to 2.0 m. The designed drop-weight test setup is depicted in Figure 1. Besides, a steel support setup was designed to provide simply support in the experiments. Drop-height is one of the investigated variables in the test. Impact loading with different level impact energies was conducted by varying the drop-height of the steel hammer. The weight of the hammer and the geometry of the hammer which contacts with RC slabs were taken as constant in all impact tests. The hammer with the weight of 200 kg had semispherical-head fabricated from high-strength steel material as shown in Figure 2 and it was dropped from heights of 1,000, 2,000 mm in order to apple impact load with input impact energies of 1.96 kJ, 3.924 kJ were applied to slab specimens. The energy levels of the impact loading were determined by considering the capacities of the measurement devices used in impact tests. Eight strain gauges were installed, eight LVDTs were affixed on the top surfaces of slab specimen and a load cell placed at the center soffit slab to measure strains, deflections and impact load, respectively, all this explained in Figure 3.

The formula used by Kiran et al., 2015 for calculating the HFRC Slabs energy absorption is:

E= N x (w x h) joules

Where,

E is the energy absorbed in joules,

w is weight of hammer in Newton,

h is the height of drop in meter and

N is the no. of impact blows.

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Figure 1 Drop weight impact machine

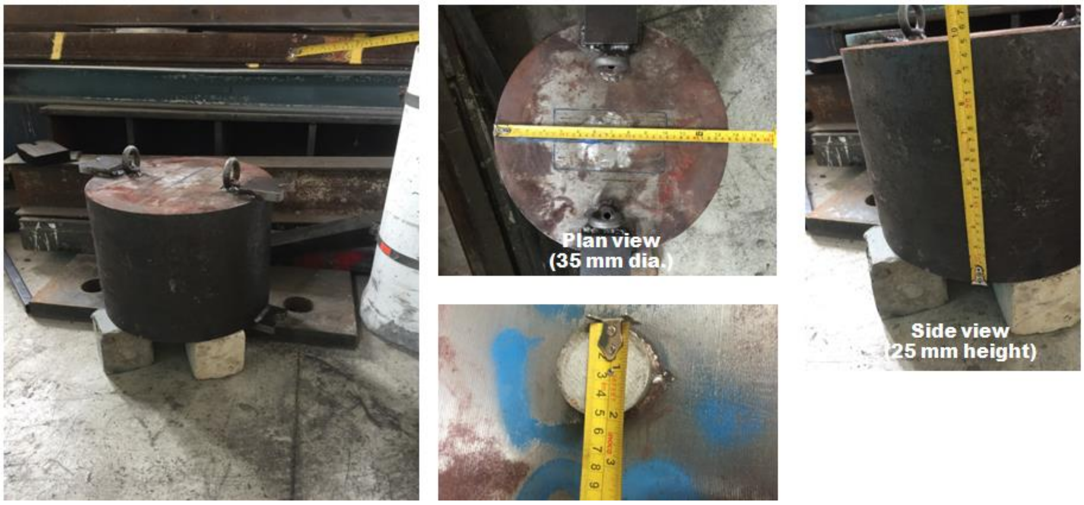

Figure 2 Details of 200 kg mass hammer

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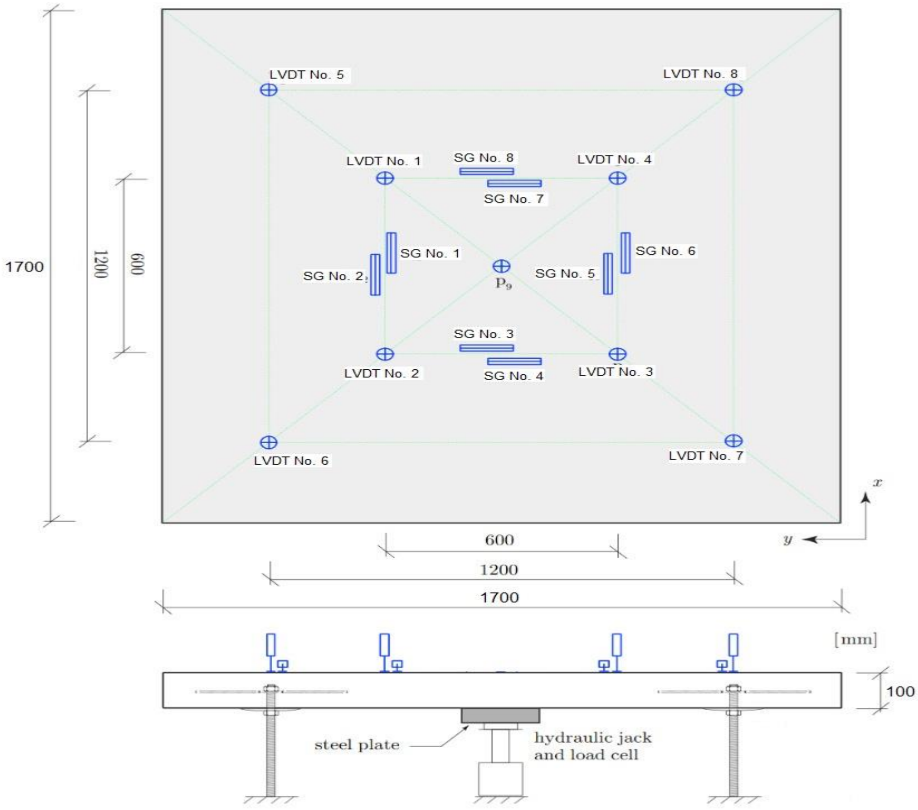

Figure 3 strain gauges and LVDs instrumentations

4. RESULTS AND DISCUSSION

The experiments focused on structural behavior of concrete slabs with different hybrid fiber mixes under the impact load were carried out. In this detailed experimental study, it was observed that slab specimens that involved in 1 m drop height were C1, M1, M2 and M3 only. Those slabs except C1 had no effects at all including no crack was spotted; so, the condition before and after the 1 m drop height for slab specimens M1, M2 and M3 were same. Whereas, slab specimens M4, M5, M6 and M7 were tested with 2 m drop height only due to no effects on slabs at 1 m drop height.

Energy Absorption of HFRC slabs

The maximum impact load and impact energy test results of the HFRC slab specimens are presented in Table 2. It was observed that, the greatest positive strain by slab specimen M1 at 2m. Whiles, M3 and M6 at 2m give the negative value.

The impact energy absorbed by hybrid fiber reinforced concrete is more than plain concrete slabs. Slab specimens M3 and M6 showed the maximum strength when compared to other mixes.

The strain rate of HFRC slabs

In dynamic tests, the strain rate is a critical parameter. A structural specimen's strain rate, on the other hand, cannot be defined because all points of the specimen have different strain rates at the same time (LEE, 2020). As a result, only the maximum strain rates at the slab specimens' tensile and compressive zones are supplied as reference values in this study, which can explain the properties of specimens during impact testing. Stain gauges were connected to slab specimens as illustrated in Figure 3 to get the strain rate, and measured strains were discriminated with regard

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to time. Figure 4 depicts the strain rate behavior for all eight M2 strain rates. These strain rates represent the strains' instantaneous slopes. Table 2 also shows the highest tensile and compressive strain rates of the specimens at the first drop.

Even after a 1m or 2m drop, almost all Slab specimens had the same strain value of 1023.969µm/m.

When the slab specimen attained maximum strain in compression and load 0.0502 in compression, it was discovered.

Table 2 Maximum Impact load of impact load test HFRC slab specimens for Load cell

Specimen	Positive values kN	Impact strength kJ	Negative values kN	Impact strength kJ
C1	1.5965	1.5965	209.4162	209.4162
M1 at 1m	0.3259	0.3259	7.2218	7.2218
M1 at 2m	6.9961	13.992	63.9098	127.8196
M2 at 1m	0.37614	0.37614	64.0853	64.0853
M2 at 2m	4.7811	9.5622	116.1845	232.3690
M3 at 1m	6.4445	6.4445	13.7666	13.7666
M3 at 2m	6.3525	12.7050	273.8944	547.7888
M4 at 2m	1.2287	2.4574	57.8331	115.6662
M5 at 2m	4.0038	8.0076	194.1283	389.5766
M6 at 2m	5.3579	10.7158	273.8944	547.7888
M7 at 2m	4.1124	8.2248	194.7469	389.4938

Where:
- ve values means: load cell was being compressed. It means, it measured how much load from the impact
+ve values means: vice versa (weight was bouncing upward)

Load deflection of impact load test of HFRC slabs:
Table 3 illustrates the maximum deflection of impact load test. Slab specimen M1 at 2m reached maximum deflection 47 mm, when the slab upward. While, M2 at 2m reached the minimum deflection 8 mm, when the slab upward also.

Crack and failure patterns
The final crack profiles of the impact test specimens are shown in Figures 6-13. The failure modes of the identical specimens were similar. Except for slab specimen C1, the fracture pattern of all evaluated slab specimens under impact loading conditions displayed several flexural cracks that steeply progressed into the compression zone. The impact event was catastrophic in the case of plain concrete C1. As shown in Figure 6, the projectile pierced the slab and caused a shear cone-shaped fracture. As a result of radial crack formation, the slab lost its integrity and gained velocity. Crack widths of all tested slab specimens are presented in Table 4.

Because the steel fiber used has a higher bonding strength, improved impact values have been recorded. Choudhary et al., 2021, found a similar pattern of improved impact strength.

Table 2 Maximum tension and compression strain rate of impact test HFRC slab specimens for strain gauges

Specimen	Tension strain rate	Compression strain rate
C1	1023.969	587.9063
M1 at 1m	60.90625	132.1875
M1 at 2m	1023.969	155.6875
M2 at 1m	1023.969	1024
M2 at 2m	135.8438	36.65625
M3 at 1m	1023.969	83.09375
M3 at 2m	1023.969	531.5

M4 at 2m	1023.969	209.8438
M5 at 2m	1023.969	550.4688
M6 at 2m	1023.969	629.8125
M7 at 2m	171.25	302.4688

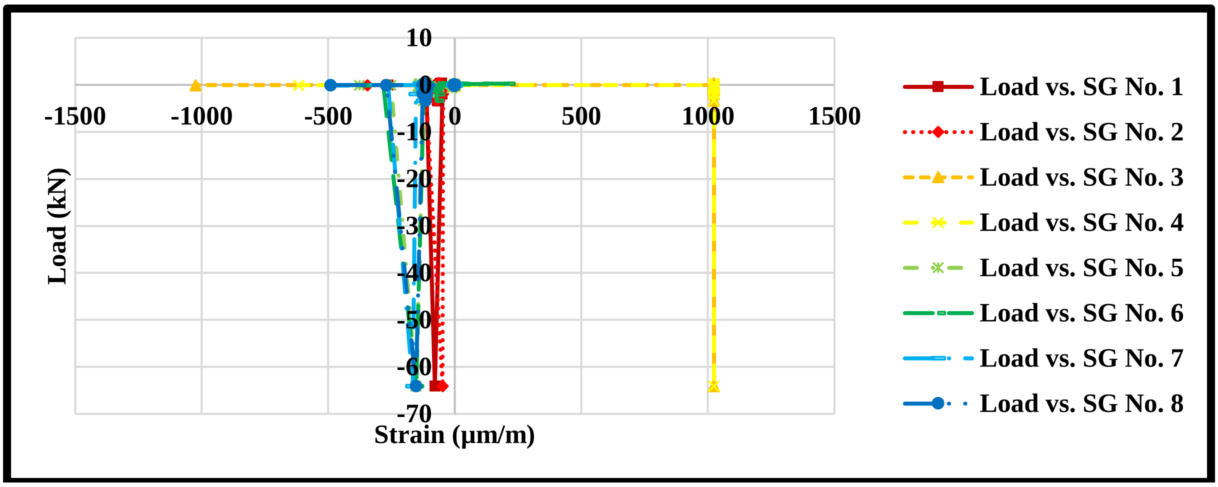

Figure 3 Load versus Strain: slab specimen M2

Table 3 Maximum Deflection (mm) of impact load test HFRC slab specimens for LVDTs

Specimen	Positive values	Negative values
C1	19.7114	19.712
M1 at 1m	17.57765	8.485038
M1 at 2m	47.03917	19.2891
M2 at 1m	14.96386	38.47593
M2 at 2m	8.088006	11.65226
M3 at 1m	33.54312	19.87261
M3 at 2m	28.21328	24.11363
M4 at 2m	40.13624	21.30734
M5 at 2m	37.93152	24.6039
M6 at 2m	37.41117	27.10039
M7 at 2m	33.93714	18.89207

Where:
+ve values means: deflection upward
-ve values means: deflection downward

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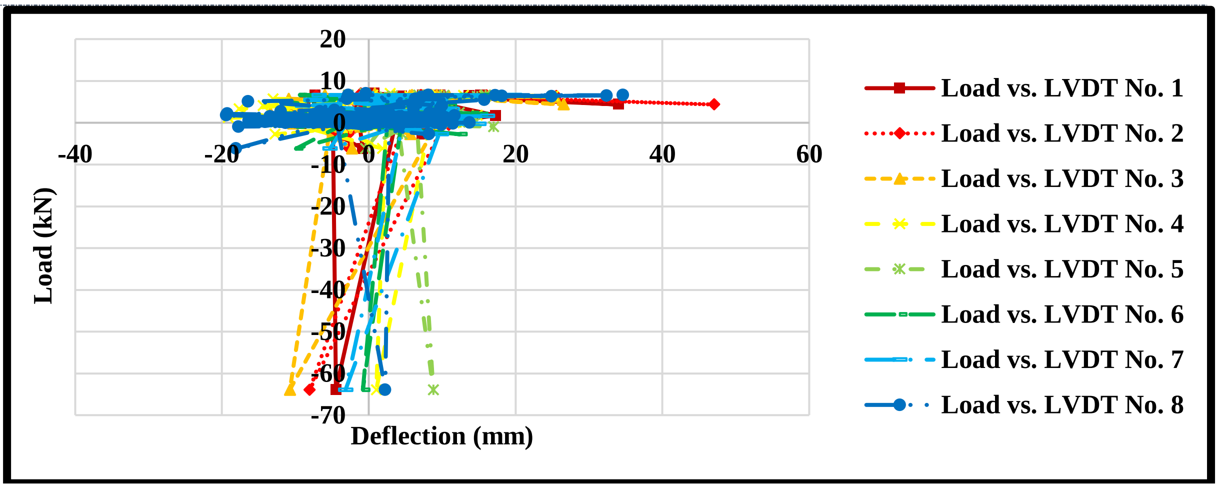

Figure 5 Load versus Deflection: slab specimen M1 at 2m

Table 4 Crack width of slab specimens after impact load

specimen	Crack width (mm)
C1- no fiber	-
M1- 1% (65/35 3D SF)	a)0.1 mm; b) 0.2 mm
M2- 0.5%(65/35 3D SF + PPF)	a) 1 mm; b) 2.5 mm
M3-1%(65/35 3D SF)+ 0.5% (PPF)	a) 0.1 mm; b) 0.2 mm; c) 1.0 mm
M4-1%(65/60 5D SF)	a) 0.1 mm
M5-0.5%(65/60 5D SF + PPF)	a) 0.1 mm; b) 0.2 mm; c) 0.3 mm.
M6-1%(65/60 5D SF) + 0.5% PPF	a) 0.1 mm
M7- 1% PPF	a) 0.1 mm; b) 0.2 mm; c) 1.4 mm; d) 1.6 mm.

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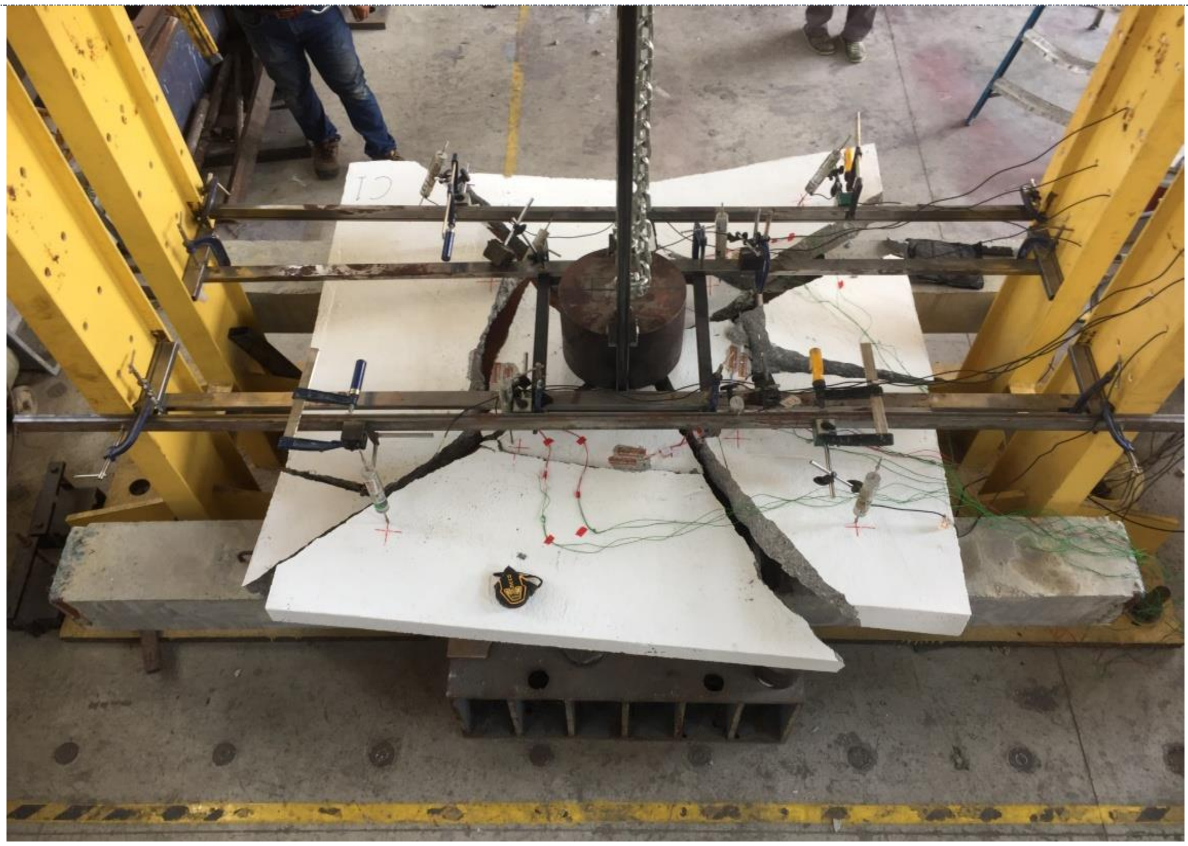

Figure 6 Final crack patterns for impact test specimen C1

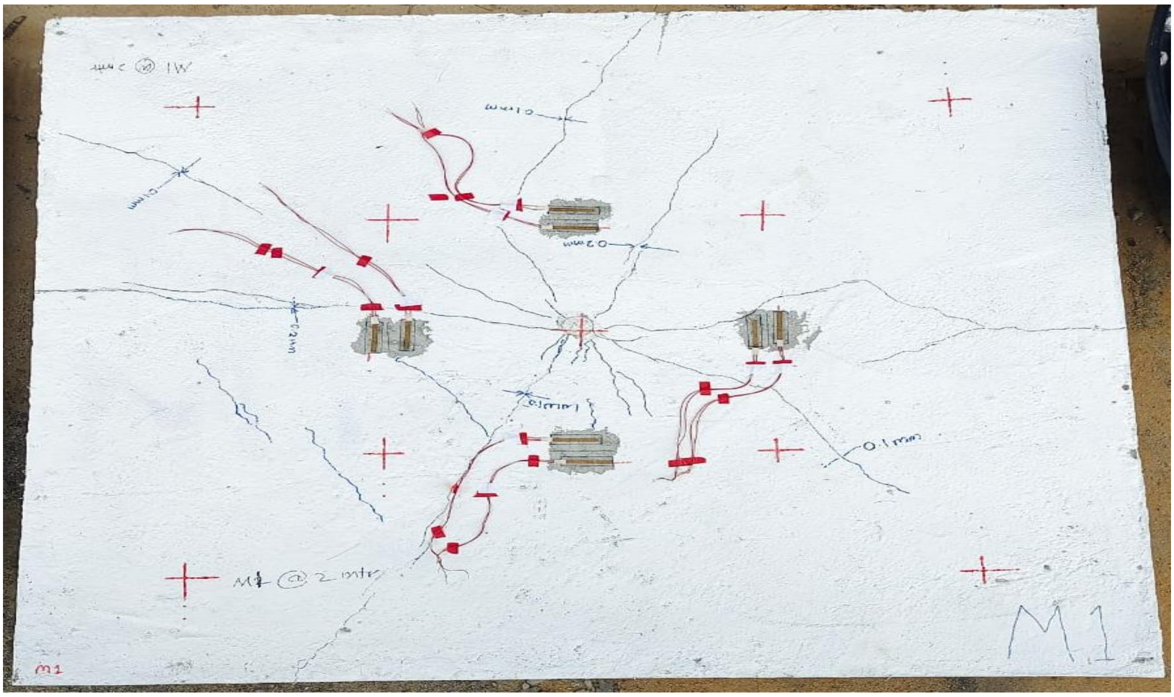

Figure 7 Final crack patterns for impact test specimen M1

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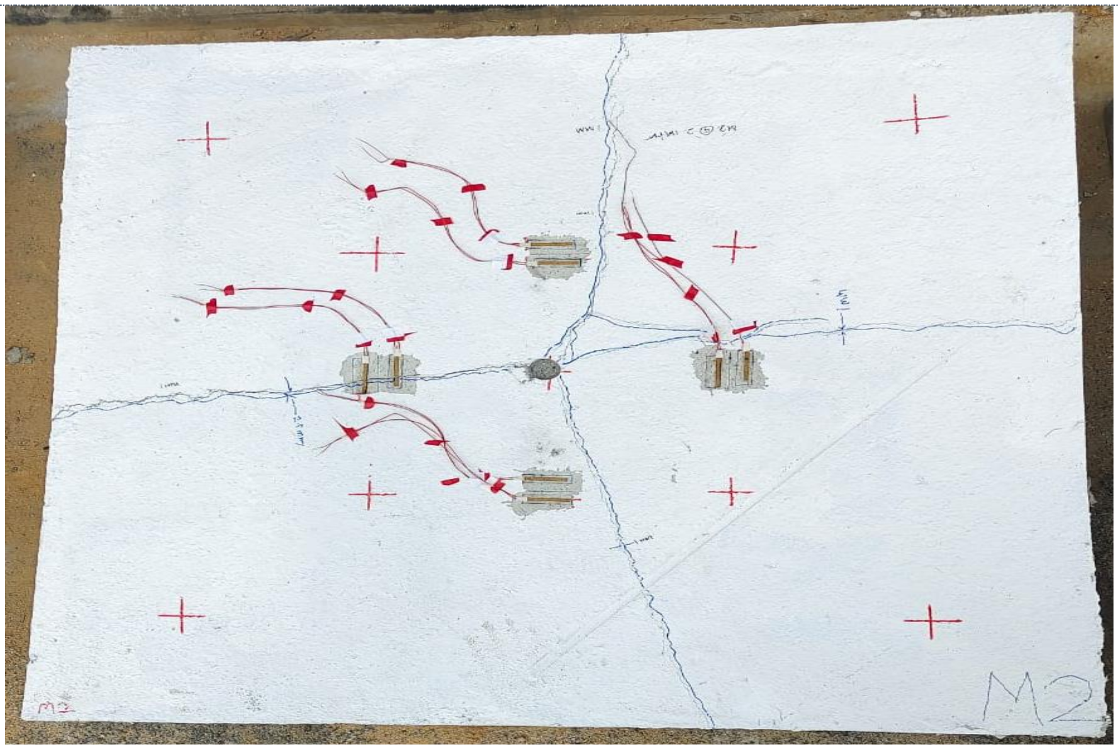

Figure 8 Final crack patterns for impact test specimen M2

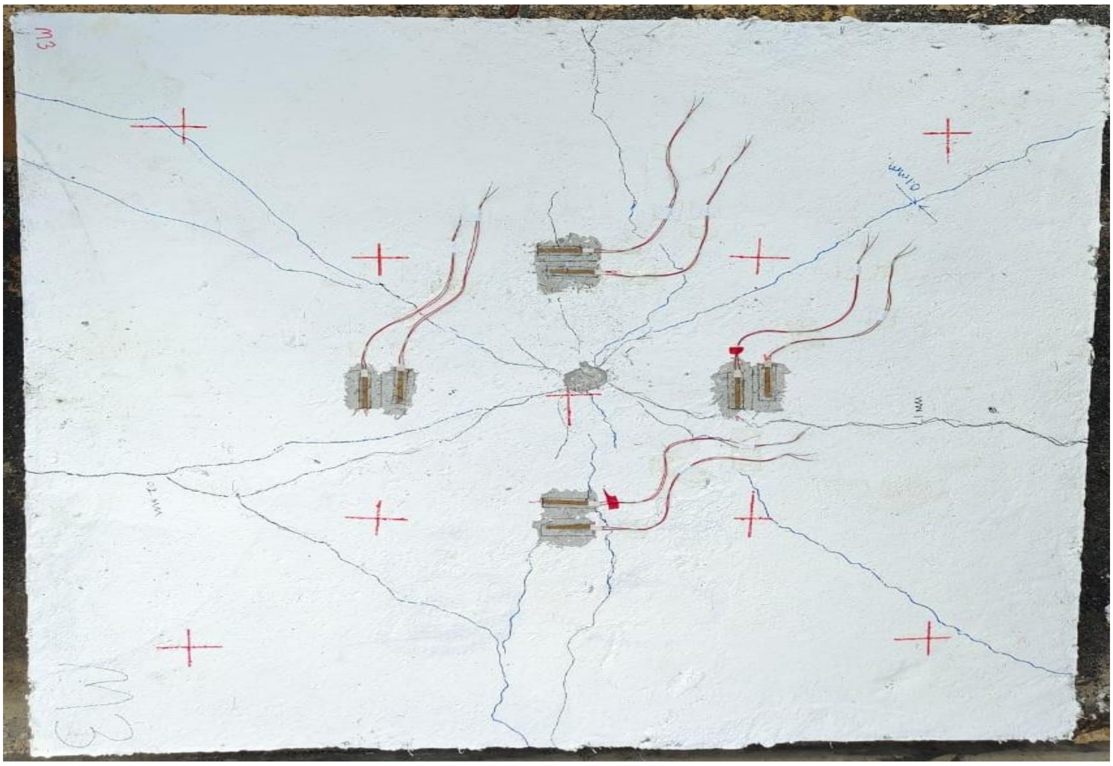

Figure 9 Final crack patterns for impact test specimen M3

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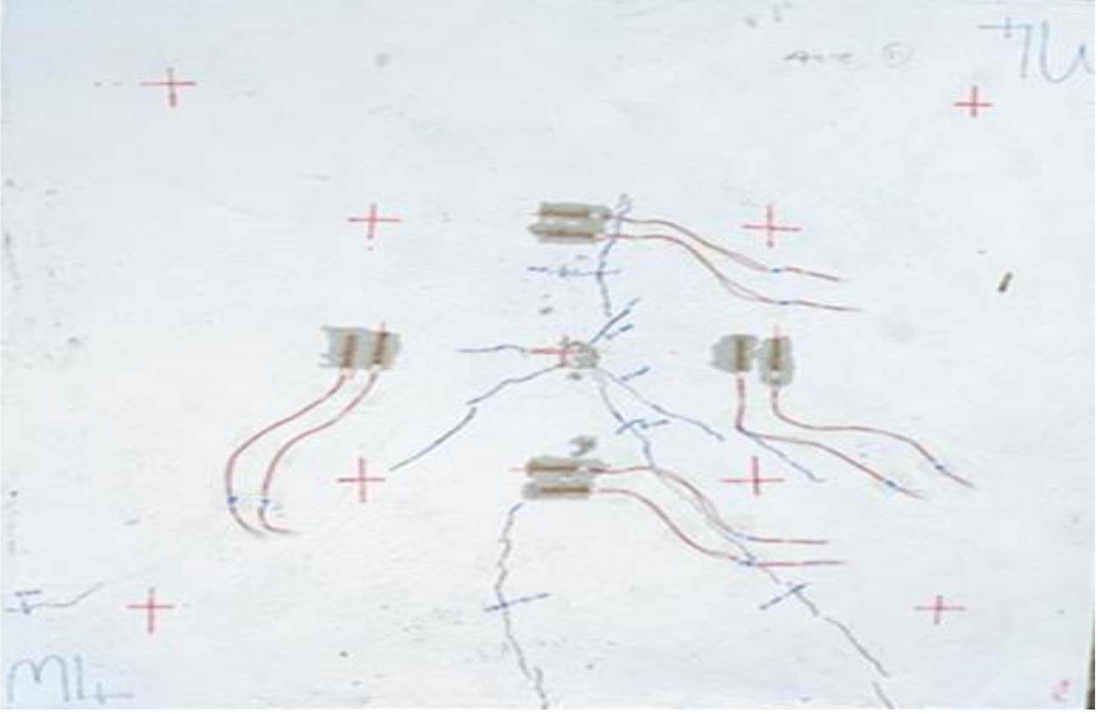

Figure 10 Final crack patterns for impact test specimen M4

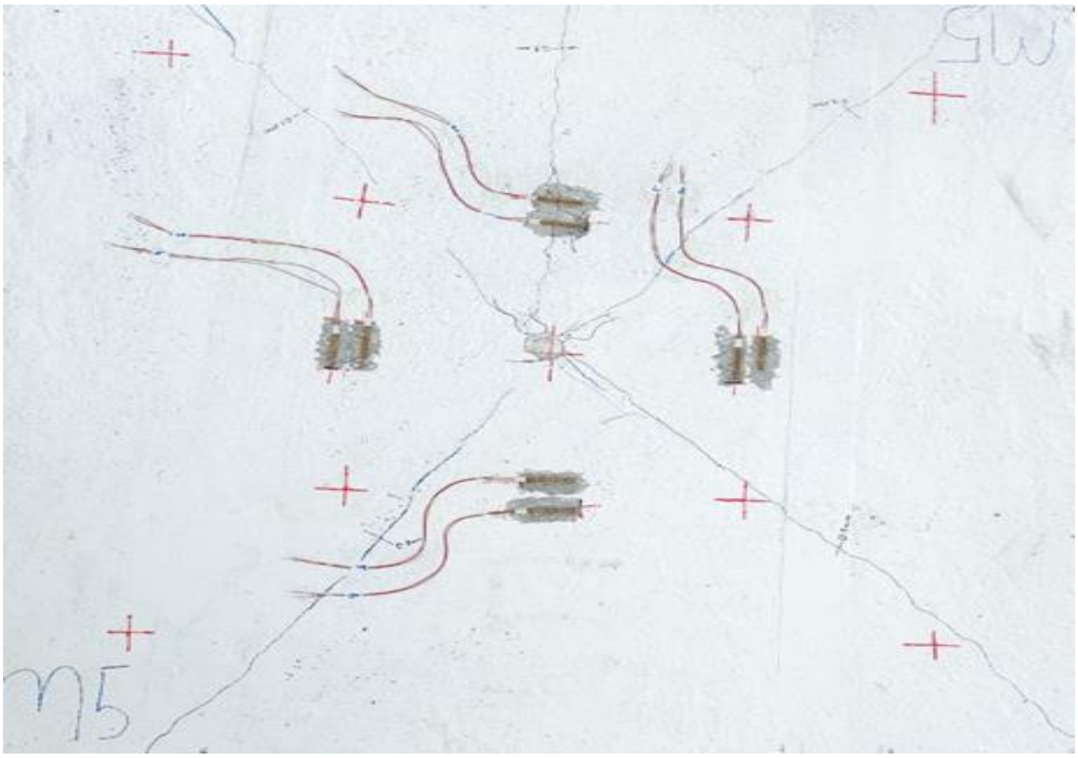

Figure 11 Final crack patterns for impact test specimen M5

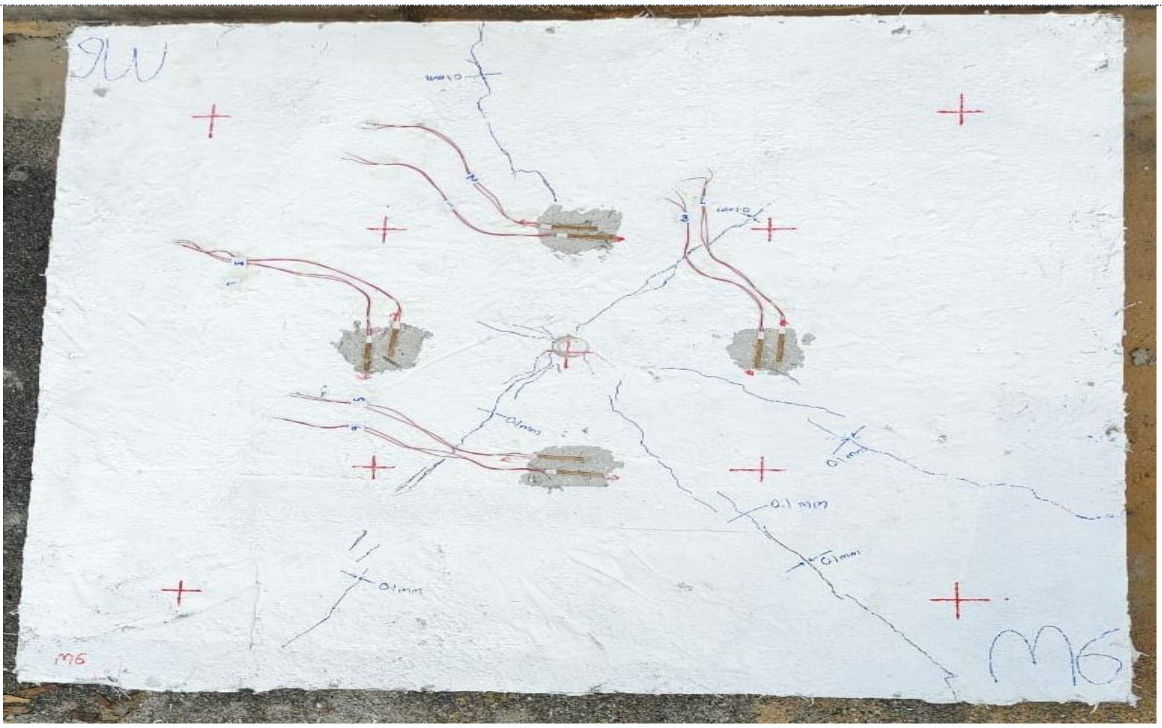

Figure 12 Final crack patterns for impact test specimen M6

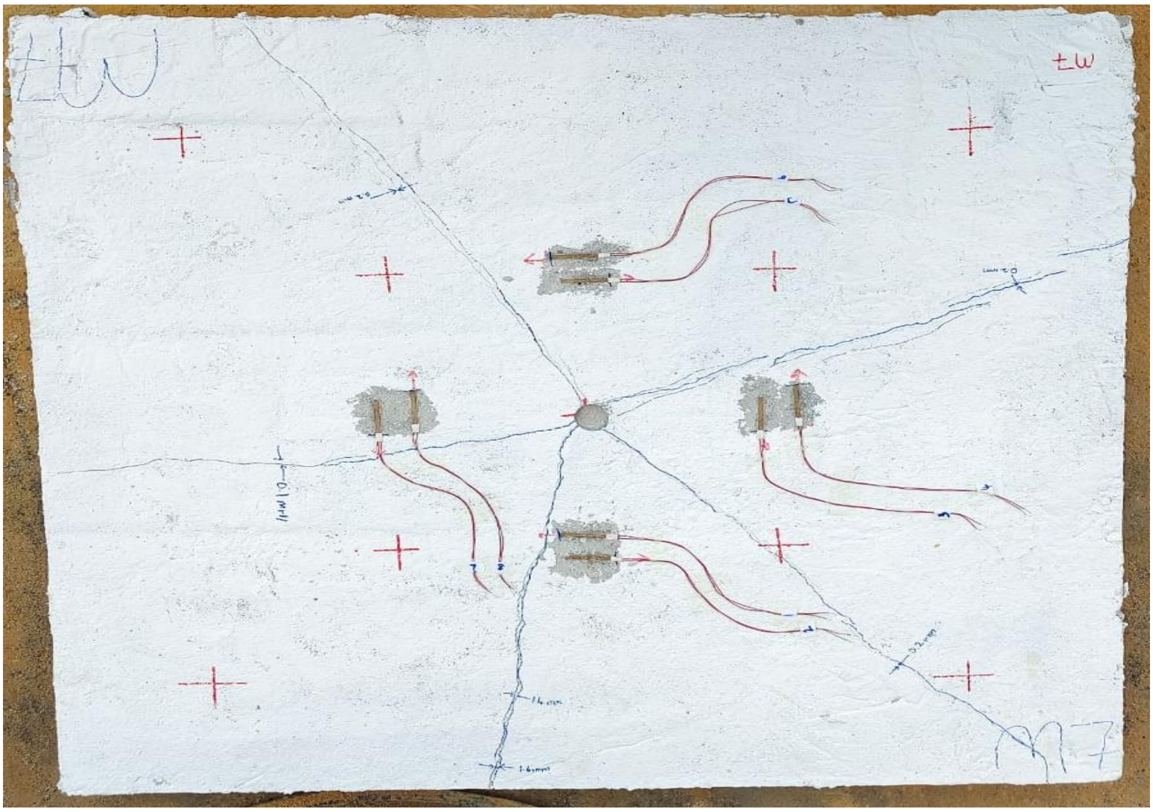

Figure 13 Final crack patterns for impact test specimen M7

5. CONCLUSION

Under impact load, the behavior of HFR reinforced with various combinations of steel and PP fibers was investigated. The following are some of the inferences that can be drawn:

-In comparison to ordinary concrete that has been exposed to an impact load, fiber reinforcing minimizes the extent of damage and maintains damaged concrete more compact. Even with mono-fiber reinforcement, slabs showed enhanced spall and cratering resistance.

- In terms of mass lost, steel-PP hybrid fiber reinforcement was found to give a significant improvement in performance under impact load when compared to mono-fiber (steel only) reinforced concrete specimens. The steel-PP combination provides outstanding impact resistance due to the extraordinary fiber-matrix bond strength, high tensile strength, and modulus of elasticity of PP fibers.

- The impact resistance of HFRC is influenced by the fiber concentration in hybrid fiber mixtures as well as the length ratio. In hybrid systems, specimens with fibers fared better on average than specimens with simply one fiber. Specimens M3 and M6, which include 1 percent SF and 0.5 percent PPF, provide the best impact resistance because they provide enough bonding (anchoring) area while remaining short enough to uniformly fill the matrix spaces between the SF and PPF.

- In comparison to PPF alone, the overall impact resistance of all PPF-steel hybrid systems was shown to be higher. The incorporation of polymer fibers in concrete can thereby increase the structure's longevity while also reducing its weight.

- Based on the findings, it can be concluded that the impact test was effective in determining the HFRC system's resistance to high loading rates such as impact and blast loads.

6. ACKNOWLEDGEMENTS

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REFERENCES

[1] Abadel, A. A., et al. "Local impact damage behavior of fiber reinforced high strength concrete slabs." (2012).
[2] Almusallam, Tarek H., et al. "Response of hybrid-fiber reinforced concrete slabs to hard projectile impact." International Journal of Impact Engineering 58 (2013): 17-30.
[3] Banthia, Nandakumar, and N. Nandakumar. "Crack growth resistance of hybrid fiber reinforced cement composites." Cement and Concrete Composites 25.1 (2003): 3-9.
[4] Choudhary, Sumit, et al. "Analysis of steel fiber reinforced concrete wall panels under compression, flexural and impact loading." Materials Today: Proceedings 38 (2021): 2471-2475.
[5] Feng, Jun, et al. "Experimental study on hybrid effect evaluation of fiber reinforced concrete subjected to drop weight impacts." Materials 11.12 (2018): 2563.
[6] Kheyroddin, Ali, Hamed Arshadi, and Javad Khedri. "The resistance of fiber-reinforced concrete with steel fibers and CFRP to drop-weight impact." Periodica Polytechnica Civil Engineering 65.2 (2021): 666-676.
[7] Kiran, T., Sadath Ali Khan Zai, and S. Srikant Reddy. "Impact test on geopolymer concrete slabs." Int J Res Eng Technol 4 (2015): 110-116.
[8] Lee, Jin-Young, et al. "Strategic use of steel fibers and stirrups on enhancing impact resistance of ultra-high-performance fiber-reinforced concrete beams." Cement and Concrete Composites 107 (2020): 103499.
[9] Mousavi, Tohid, and Erfan Shafei. "Impact response of hybrid FRP-steel reinforced concrete slabs." Structures. Vol. 19. Elsevier, 2019.
[10] Marar, Khaled, Özgür Eren, and Tahir Celik. "Relationship between impact energy and compression toughness energy of high-strength fiber-reinforced concrete." Materials letters 47.4-5 (2001): 297-304.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[11] Marzouk, Hesham, and Hesham Othman. "Performance of UHPFRC Plates under Repeated Impact Load." International Interactive Symposium on Ultra-High Performance Concrete. Vol. 1. No. 1. Iowa State University Digital Press, 2016.

[12] Schrader, Ernest K. "Impact resistance and test procedure for concrete." Journal Proceedings. Vol. 78. No. 2. 1981.

[13] Soe, Khin T., Y. X. Zhang, and L. C. Zhang. "Impact resistance of hybrid-fiber engineered cementitious composite panels." Composite structures 104 (2013): 320-330.