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Effect of High-Velocity Impact Loading on Concrete Slabs Reinforced by Metallic Strips from Soft Drink Cans as Fiber

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ABSTRACT

The idea of enhancing concrete slabs' ability to resist impact has been discussed in this study and, specifically, the use of soft drink can strips fibers (SDCSF). Concrete structures are classified as brittle material when happen to be exposed to impact loads like the firing of guns. Some of the past research works revealed that subjected to impact loads, the concrete structures disintegrated into several pieces. And because of the brittleness, fibers are incorporated into concrete at various ratios of 0. 5%, 1%, and 1.5% mean weight of cement and various proportions of 3cm, 6cm, and 9 cm to enhance concrete's resistance. Squire slab specimens with the dimension of (500 mm × 500 mm) and thickness of 50 mm. Ten specimens were subjected to high-velocity impact load by gunfire from a weapon M16, bullet diameter 7.62 mm, from a distance of 15 m. The arrangement used was to impact a single point (one bullet) at the centre of each panel. The research found that using such a type of fiber with different percentages and lengths could increase the resistance impact load. Moreover, the results showed that reducing the spalling area, the scabbing area, and reducing the redial crack length. It can be concluded that the spalling area of specimens with 1.5% soft drink can strips and 9 cm length at 28 days decreased by 21.48% compared to the reference sample (R). The scanning area of specimens with 1.5% soft drink can strips and 9cm length at 28 days was decreased by 24.72% compared to the reference sample (R). The redial crack length of specimens with 1.5% soft drink can strips and 9cm length at 28 days was decreased by 29.32% compared to the reference sample (R).

1. INTRODUCTION

High-velocity impact loads from certain distances cause severe cracking and damage to the concrete material [1, 2]. Adding fibers to reinforcement concrete can increase engineering properties such as fracture toughness, flexural strength, impact resistance, and fatigue [3]. Soft Drink Cane Strips reinforced cementations composites (SDCS) have been used to improve the flexural and tensile ductility of concrete structural elements.

Many researchers and studies have investigated the effect of high-velocity impact loads on fiber-reinforced concrete.

Almusallam et al. [4] presented the impact response of CFRP-strengthened reinforced concrete (RC) panels subjected to non-deformable projectiles. Both control and CFRP-strengthened RC slab panels were tested using hemispherical nosed steel projectiles at varying impact velocities. The study combines experimental and numerical investigations to assess damage, including penetration depth, crack formation, spalling, scabbing, and CFRP sheet fracture. A practical and efficient numerical method using LS-DYNA is proposed for analyzing the impact response of CFRP-strengthened RC structures. Key findings include increased ballistic limit velocity (by 18%) and perforation energy (by 56.7%) due to CFRP strengthening, reduced front crater damage, and containment of concrete fragments.

Recent research by Al-Numan [5] has demonstrated that the incorporation of Styrene-Butadiene Rubber (SBR) and steel fibers significantly enhances the high-velocity impact resistance of polymer-modified concrete (PMC). The study found that the addition of SBR reduced the penetration depth and scabbing area by 5-17% and 15-35%, respectively, while the inclusion of steel fibers further decreased these metrics by 28-39% and 64-95%. Additionally, the mechanical properties, including compressive strength (48-64 MPa), splitting tensile strength (4.2-7.8 MPa), and flexural strength (5-8 MPa), were notably improved.

Richardson et al. [6] examined the role of polypropylene fiber in enhancing the impact resistance of reinforced concrete through experimentation involving the use of several 7.62 mm caliber bullets. The findings indicated that the inclusion of polypropylene fiber had a substantial positive effect on the energy absorption mechanism and enhanced the impact resistance. Furthermore, it has a substantial effect on reducing spalling and the extent of back face scabbing on reinforcing plates, in addition to limiting redial cracks.

Najim [7] examined the influence of steel fiber concentration and the combined impact of rice husk ash (RHA) and high-range water reducing agent (HRWRA) on the impact resistance of the resulting matrix. In addition, he conducted an analysis of the mechanical characteristics pertaining to this particular type of concrete. The study looked at the tensile strength, flexural strength, damping capacity, apparent porosity index, drying shrinkage, impact (low and high velocity), and splitting tensile strength of high-performance concrete. Researchers tested the concrete at various curing ages while incorporating different amounts of steel fiber.

Al-Dulaimi [8] considered the mechanical properties and response of ferro cement slabs under impact loading conditions, encompassing both high and low velocities. The results indicated a decrease in spalling and scabbing areas with an increase in polymer content and the number of wire mesh layers in comparison to the reference mixes. Increasing the proportion of polymers led to improved mechanical properties.

Hülsewig et al. [9] studied the outcomes of colliding deformable projectiles, traveling at velocities of up to 400 meters per second, with reinforced concrete slabs. The study found that the depth of penetration decreased compared to expectations when colliding with rigid projectiles, and this difference further increased with higher velocities.

In the study by Jacobsen et al. [10] investigated how projectiles affect 100 mm reinforced concrete slabs through experiments and numerical simulations. Findings revealed that reinforced concrete slabs demonstrated resistance, to penetration, then slabs showing decreased penetration depth and enhanced energy absorption capabilities when subjected to 20 mm ogive nose steel projectiles.

Al-Hadithi [11] conducted a research study to boost the strength, structural integrity and impact resilience of concrete by adding butadiene rubber (SBR) at different polymers, to cement weight ratios (3%, 5%, and 10%). The study included creating test samples for assessments; cubes for measuring compressive strength prisms for testing flexural strength and panels for conducting low and high velocity impact tests. Furthermore, reinforced polymer modified concrete beams were examined to evaluate their performance. The findings showed an enhancement in all tested properties of the polymer modified concrete compared to the concrete with particularly noticeable improvements, in both low velocity and high velocity impact resistance.

Abd and Ahmed [12] studied how different loads affect the behavior of self-compacting concrete (SCC). In their research, on SCC mixtures two types of cement were used; Standard Portland Cement (OPC) and Portland Limestone Cement (PLC). Carbon Fiber Reinforced Polymer (CFRP) was added to the mixtures as reinforcement a practice, for enhancing the performance of masonry walls. The inclusion of CFRP significantly improved the impact resistance of the mix compared to SCC mixes. Among the two types examined concrete slabs reinforced with OPC SCC showed the level of impact resistance. Conversely slabs made with PLC exhibited still comparable results.

Abbas and Rakaa [13] carried out tests to study the bending properties of Self-compacted concrete (SCC) beams reinforced with rebars and steel fibers. The beams were made with expanded polystyrene concrete (EPS). The inclusion of steel fiber reinforcement led to an increase, in the bending strength of the beams, under examination.

The relationship between the compressive strength of concrete and the penetration depth at different impact velocities was investigated by Soe et al. [14]. Their results indicated that the penetration depth of panels on lower compressive strength was greater for similar impact velocity. Thus, except for an impact velocity of approximately 300 m/s, hybrid-fiber Engineered Cementitious Composite (ECC) reinforced with 1.75% Polyvinyl Alcohol (PVA), and 0.58% Steel Fibers (SF) panels with higher compressive strength (67 MPa) resulted in a penetration depth less than that of ECC reinforced with 1.5% PVA, and 0.5% SF panels. The specimens with compressive strength of 90 MPa had the lowest penetration depth at 300 m/s.

This study aims to improve the high-velocity impact resistance of concrete by incorporating soft drink cane strips as fibers.

2. EXPERIMENTAL STUDY

2.1 Materials

2.1.1 Cement

The cement utilized in the study is locally produced as Al-mass ordinary Portland Cement (OPC), which is correspondent ASTM type 1 having specific gravity of 3.15 and Blaine fineness of 2500 cm^2/g was used and it satisfies the Iraqi standard IQS NO.5 1984.

2.1.2 Fine aggregate

Al-Ukhaider natural sand of 4.75 mm maximum size, a specific gravity of 2.66%, and a sulfate content of 0.08% was used for concrete mixes in this investigation within the requirements of Iraqi specification No. 45/1984.

2.1.3 Coarse aggregate

The washed coarse aggregates were from the Al-Nibaey region. having a specific density of 2.71 and a maximum size of 10 mm, it conforms to the Iraqi specification No.45/1984.

2.1.4 Water

Ordinary drinking water in the city of Ramadi, Iraq, was used to mix and curing the concrete specimens.

2.1.5 Soft cane fibers

In this research, soft drink can from various sources were used in the experimental work. The soft can (SDC) body can be divided into strips, as depicted in Figure 1, of different lengths (3, 6, and 9 cm) and added to the concrete mix in different percentages (0.5%, 1%, and 1.5%) by weight of cement. Soft drink can strips fibers (SDCSF) are efficient fiber materials made up of tin, steel, and aluminum that have high tensile strength when implemented in side-reinforced concrete.

Figure 1. Cutting soft drink cans into strips

Table 1. Mix proportions of materials

Concrete Mix	Mixing Ratio	Cement (kg)	Sand (kg)	Aggregate (kg)	W/C Ratio (kg)	Ratio Fiber	Fibers (Kg)	Length Fibers	Coring Conditions (Day)
R	1:2:3	7.2	14.4	21.6	3	0	0	0	28
1	1:2:3	7.2	14.4	21.6	3	0.5%	36	3	28
2	1:2:3	7.2	14.4	21.6	3	0.5%	36	6	28
3	1:2:3	7.2	14.4	21.6	3	0.5%	36	9	28
4	1:2:3	7.2	14.4	21.6	3	1%	72	3	28
5	1:2:3	7.2	14.4	21.6	3	1%	72	6	28
6	1:2:3	7.2	14.4	21.6	3	1%	72	9	28
7	1:2:3	7.2	14.4	21.6	3	1.5%	108	3	28
8	1:2:3	7.2	14.4	21.6	3	1.5%	108	6	28
9	1:2:3	7.2	14.4	21.6	3	1.5%	108	9	28

Figure 2. Concrete slabs (500 ×500 × 50) mm

Figure 3. Cube and cylinder samples

2.2 Mix proportions

In this research, the materials were prepared in the lab of concrete, college of engineering, university of Anbar by provided reference mixture (R) without fibers, the concrete mixture was designed at a preparation 1:2:3 (cement, sand, aggregate), respectively. Cement mixed with the sand and the aggregate was poured into a mechanical mixer of the capacity (0.1 m^3) operated by electrical power until the dry mix became homogenous and finally water was added and mixing continues until uniform mix is obtained, this procedure is similar to the method used by Fukuchi and Ohama [15]. Fibers were added to enhance the concrete mixtures (1, 2, 3, 4, 5, 6, 7, 8, and 9) in varying percentages (0.5%, 1%, and 1.5%) relative to the weight of cement. The fibers were also of different lengths (3, 6, and 9 cm), as indicated in Table 1. In Figure 2, a concrete slab of (500 × 500 × 50 mm) was used. In Figure 3, cubes of (100 × 100 × 100 mm) and cylinders of (100 × 200 mm) were used to conduct impact tests. Compressive and splitting tensile strength tests were performed after 28 days.

2.3 Methodology

Ten slab specimens (500 × 500 × 50) mm were tested under high velocity impact loading using firegones from weapon M16 using 7.62 mm bullets shown in Figure 4.

Figure 4. Gunshots from weapon M16

The specifications for armor-piercing bullets are given in Table 2.

Table 2. Specification of armor-piercing bullets

Bullets Dia. (mm)	Muzzle Velocity (m/sec)	Pressure (kg/cm^2)	Mass (gm)
7.62	714-756	2800	7.47-7.87
9.00	380-410	7047	7.32-7.87
12.7	810-825	3100	47.4-49.0

After a curing time of (28 days) the specimens were fixed inside the manufactured base to avoid any movement. The centers of the slabs were indicated by a marker pen. Each slab was subjected to a single shot (one bullet) at the center. The horizontal shooting was done from a distance (15 m) and after shooting, the penetration occurred, and the general condition of the specimen after the test was observed and photographed as shown in Figure 5.

Figure 5. The specimen after gunshots

3. RESULTS AND DISCUSSION

3.1 Mechanical test

The incorporation of 1.5% soft drink can strips as fibers (SDCSF) into the concrete mix significantly improved both the compressive and tensile strengths of the concrete. After 28 days, specimens with 1.5% SDCSF and a length of 9 cm exhibited a compressive strength of 65.7 MPa, compared to 48.7 MPa for the reference sample see Figure 6. Similarly, the tensile strength increased to 5.87 MPa from 3.42 MPa for the reference sample. This enhancement in mechanical properties can be attributed to the fibers' ability to bridge cracks and distribute stress more evenly throughout the concrete matrix, thereby delaying the onset of failure, as shown in Table 3, Figure 6 and Figure 7.

3.2 Impact test

The impact resistance of concrete slabs reinforced with SDCSF was evaluated by examining the spalling area, scabbing area, and radial crack length after impact testing. The results indicated a significant reduction in damage for specimens with 1.5% SDCSF and 9 cm length compared to the reference sample. Specifically, the spalling area decreased by 21.48%, the scabbing area by 24.72%, and the radial crack length by 29.32%, see Table 4 and Figures 8-10.

Table 3. Mechanical test results

Fibers Length	**3 cm**			**6 cm**			**9 cm**			**R**
Fibers Ratio	**0.5%**	**1%**	**1.5%**	**0.5%**	**1%**	**1.5%**	**0.5%**	**1%**	**1.5%**	
Compressive (MPa) Concrete Cubes	56.9	48.5	48	58.1	52.4	50.9	59.6	60.1	65.7	48.7
Splitting Tensile (MPa) Concrete Cylinders	4.61	4.62	5.35	5.23	4.53	5.83	5.27	5.34	5.87	3.42

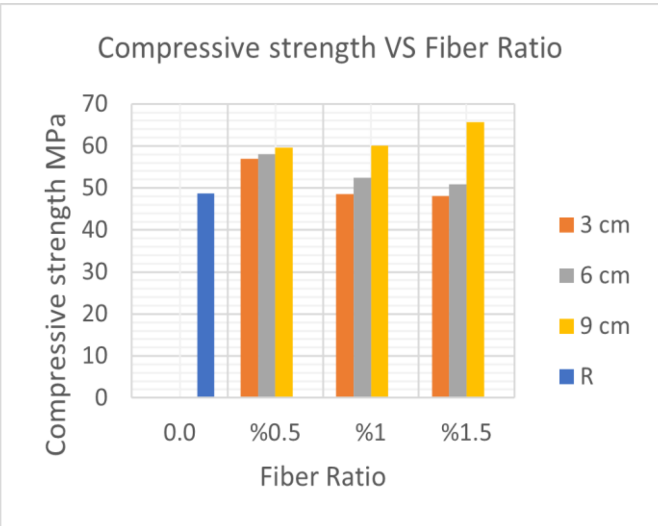

Figure 6. Compressive strength with fiber ratio

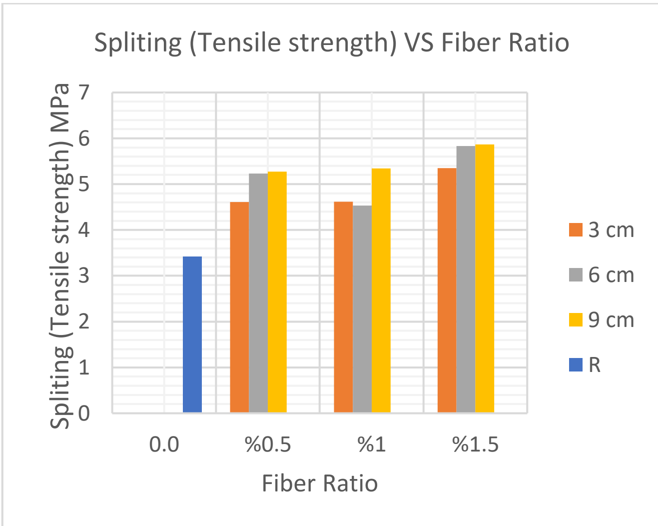

Figure 7. Tensile strength with fiber ratio

Table 4. High velocity impact test results

Fibers Length	**3 cm**			**6 cm**			**9 cm**			**R**
Fibers Ratio	**0.5%**	**1%**	**1.5%**	**0.5%**	**1%**	**1.5%**	**0.5%**	**1%**	**1.5%**	
Spalling area (cm^2)	75.89	65.90	61.24	73.14	70.88	46.08	56.75	55.95	39.70	184.82
Scabbing area (cm^2)	173.20	113.09	92.62	119.40	139.55	103.86	83.80	82.19	78.54	317.62
Crack length(cm)	34.30	29.40	22.13	24	21.60	20.20	22.50	19.30	17.50	59.68

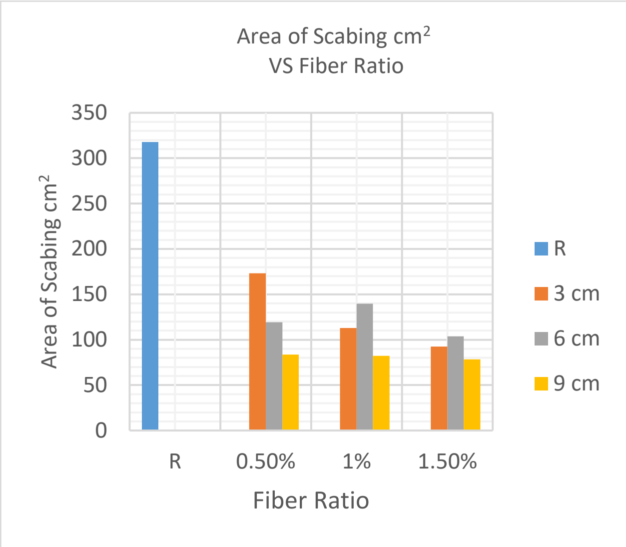

Figure 8. Area of scabbing with fiber ratio

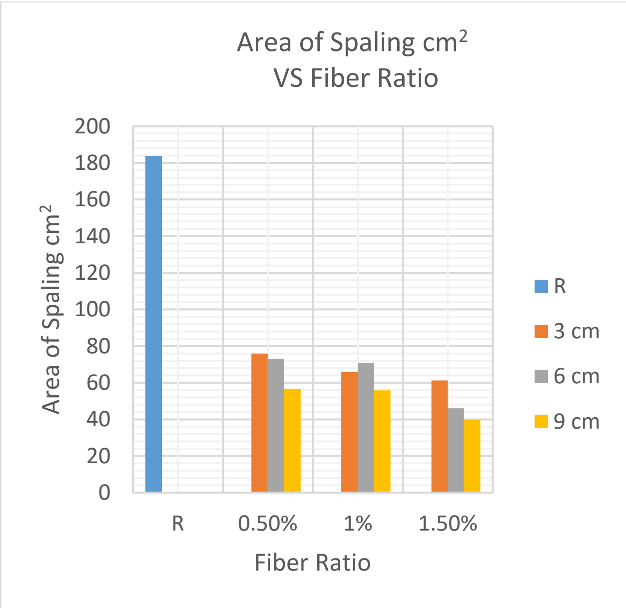

Figure 9. Area of spalling with fiber ratio

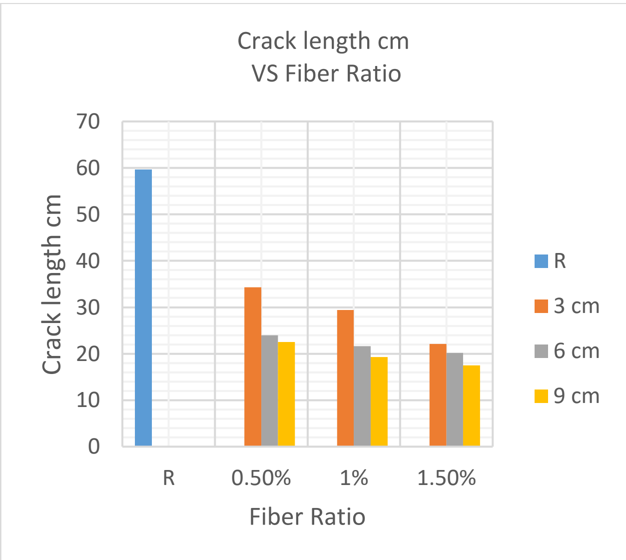

Figure 10. Crack length with fiber ratio

4. MECHANISMS OF IMPROVEMENT

4.1 Tensile strength enhancement

The incorporation of SDCSF boosts the tensile strength of concrete by increasing its resistance, to impacts. These fibers reinforce the structure keeping it intact and minimizing the chances of cracks spreading or surface damage occurring.

4.2 Energy absorption

The metallic strips from soft drink cans enhance the concrete's ability to absorb energy. When there are collisions these fibers aid, in dispersing the energy leading to less severe damage.

4.3 Crack bridging

The fibers help connect cracks that develop when under pressure stopping them from expanding into cracks that may cause spalling or scabbing. This process works well in decreasing the length of cracks seen during impact testing.

Appindex A shows indications of the failure patterns observed in slabs following the impact test.

5. CONCLUSION

In this research, Soft Drink Cans Strip Fibers (SDCSF) were incorporated to enhance the impact resistance and mechanical properties of concrete. The SDCSF were added in varying percentages (0.5%, 1%, and 1.5%) and lengths (3 cm, 6 cm, and 9 cm). The key findings are summarized below:

1. Adding SDCSF to concrete mixtures significantly improved compressive strength. For instance, specimens with 1.5% SDCSF and a length of 9 cm exhibited a compressive strength of 65.7 MPa at 28 days, compared to the reference sample R with 48.7 MPa.
2. The addition of SDCSF also improved the strength. Samples containing 1.5% SDCSF and measuring 9 cm in length reached a strength of 5.87 MPa after 28 days compared with the reference sample R which achieved 3.42 MPa.
3. The utilization of SDCSF enhanced the resistance, to impacts leading to decreased instances of spalling, scabbing and the formation of cracks. Specifically, there was a 21.48% decrease in spalling area a 24.72% reduction, in area affected and a 29.32% shorter length of cracks observed in samples that included 1.5% SDCSF with a length of 9 cm when compared to the standard sample R.
4. After the first crack appears, the bridging effect prevents further crack propagation by distributing stress more evenly.
5. Added Soft Drink Can Strip Fibers (SDCSF) improve concrete's impact resistance. These fibers act as continuously supported bridges within the elastic matrix, preventing crack spread. Practical advantages include improved tensile properties, reduced fragmentation, and enhanced shock load resistance. Furthermore, increased compressive strength is linked to improved impact resistance as a result of the reinforcement, from SDCSF.
6. Enhancing the strength is linked to resistance, against impacts.

Our research shows that adding 1.5% SDCSF to the mix along with fibers improves both strength and resistance, to high-velocity impacts.

6. RECOMMENDATIONS FOR FUTURE RESEARCH

Further studies may explore kinds of reused materials that share characteristics akin, to the strips from soda cans like metal scraps or plastic components to evaluate how they can improve the durability of concrete, against impacts.

Conduct experiments with a wider range of fiber lengths, widths, and ratios to discover the dimensions and proportions that provide superior impact resistance and mechanical strength.

Develop and validate numerical models using software to simulate high-velocity impacts on fiber-reinforced concrete. This can provide deeper insights into the failure mechanisms and help optimize mix designs before physical testing.

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NOMENCLATURE

SDCS	Soft Drink Cane Strips
PMC	polymer modified concrete
SBR	Styrene – Butadiene rubber
RHA	rice husk ash
HRWRA	high range water reducing agent
SCC	self-compacting concrete
OPC	Ordinary Portland Cement
PLC	Portland Limestone Cement
CFRP	Carbon Fiber Reinforced Polymer
EPS	Expanded Polystyrene concrete
ASTM	American Society for Testing and Materials
IQS	Iraqi standard
SDCSF	Soft drink cans strips fibers

APPENDIX

Failure patterns of slabs after impact test

Front Reference (R)

Front 0.5% - 3cm


Back Face 0.5% - 3cm

Front 0.5% - 6cm


Back Face 0.5% - 6cm

Front 1.5% - 3cm


Back Face 1.5% - 3cm

Front 1.5% - 6cm


Back Face 1.5% - 6cm


Front 1.5% - 9cm


Back Face 1.5% - 9cm

Front 1 % - 3cm


Back Face 1% - 3cm

Front 1% - 6cm


Back Face 1% - 6cm


Front 1% - 9cm


Back Face 1% - 9cm