Impact Resistance Investigation of Fibre Reinforced Concrete Having GFRP Rebars in Last Two Decades

Shehryar Ahmed[1], Majid Ali[1]

[1]*Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan*

***Abstract*: The aim of this paper is to review the impact strength of different concrete composites reinforced with fibres and GFRP rebars. These composites were investigated using different testing methods. The mechanism of impact testing, using state of the art equipment to simplified apparatus done by various researchers on prototypes and on real scale, is presented. A brief overview of the parameters used in these methods is also discussed. The properties of various fibres and performance of GFRP rebars in enhancing the dynamic properties are highlighted and conclusions drawn are compiled to have a better understanding of the effectiveness of these modifications against impact loading. The outputs of these methods in terms of predicting the actual behavior of fibre reinforced concrete for real life application based on their properties are reported. The mechanism of prototype testing in regard to the implementation of testing results for actual structural members is discussed by identifying the analytical constraints in impact testing.**

***Keywords*: Fibre reinforced concrete, GFRP rebars, impact resistance, prototype testing.**

I. INTRODUCTION

Impact loading due to events such as blasts create high intensity forces in the form of waves that develops sudden deformation in a structure exposed to it. Blast impact effects the structure using two components. One is the striking of high velocity explosive that results in to damage, the moment it comes in contact to the structure. Second component is the shock wave produced by the blast that created intensified vibration in the structure. The damage caused can be either small in terms of defragmentation of the material of structure or can be a complete failure of the structure. Various researches have been done to study the effects of impact loading on reinforced concrete members. The literature indicates that over the past two decades, impact testing on behavior of reinforced concrete has moved towards the mitigation of negative results with addition of other materials including fibres and FRP rebars. Researchers have conducted impact testing on reinforced concrete members using state of the art equipment as well as simplified test set ups. The analytical validation using numerical modeling along with FEM analysis supported the testing approaches in case of well instrumented equipments but in case of simplified test setups, the differences in results vary from minimum to significant. A lot of researches have been done previously by conducting small scale and full-scale blast explosion to study the actual behavior of reinforced concrete members. These include blast testing of reinforced concrete panels, bridge barrier, slabs, columns and beams. A part from that bridge piers have been tested on full scale using blast to study the impact of vehicle collisions.

Full scale blast testing has been performed in various research programs by detonating varying amounts of trinitrotoluene (TNT) explosives to study the effects of explosive charge, contact angle and distance. The failure phenomena in reinforced concrete was recorded mostly by pressure transducers, strain gauges, accelerometers and high-speed recording cameras. The outputs of these tests were mostly in the form of impact resistance, dynamic elastic modulus and dynamic incremental factors. Such tests have been mostly validated using analytical equations and LS-DYNA software by modeling the blast impact. A number of researches on prototype RC members have been done to investigate their impact resistance. ACI 544.2R-89 [1] defines two types of instrumented impact test methods based on kinetic energy. One is the drop weight test method in which a varying mass can be dropped from varying height to study its impact on a structural member like beam or slab. Other method is the pendulum type charpy's impact test method in which a hammer of varying weight from a varying angular distance is released to study its impact on a structural member like beam, column or wall panel. Simplified drop weight method uses the sum of repetition of blows to have a quantitative estimate of the energy absorbed by specimens. This approach is beneficial for relative comparison between various specimens of fibre reinforced concrete (FRC) and normal concrete. Improved performance and relative impact resistance of FRC with different thickness has been studied in previous studies. High strain rate impact methods can be classified in to four classes based on the effect produced due to impact. These methods are based on kinetic energy, potential energy, utilization of hydraulic machines and stress wave propagation mechanisms [2].

Impact load resistance of fibre reinforced composites has been investigated by many researchers. Non-natural fibres like polypropylene, steel, GFRP, etc. have been used most of the times due to their durability as compared to natural fibres. Literature suggests that inclusion of fibres can increase the performance of reinforced concrete. Fibres hold the fragments against spalling, resulting in higher impact resistance capacity. A number of researches done on FRC include near and far field blast testing, well instrumented full-scale testing, simplified prototype testing. The performance of FRC during impact testing is observed using high speed cameras. The post-impact analysis of fibre-concrete relation is carried out mostly using scanning electron microscope (SEM) imaging. Strength and impact resistance capacity has been analytically validated in various researches but the fibre-concrete relation after blast in terms of residual bonding strength still lacks the analytical validation to achieve real behavior. A part form that literature shows the investigation of post blast residual strength using static tests.
Aspects of using glass fibre reinforced polymer (GFRP) rebars in concrete instead of steel rebars keeping in view the strength requirements have been explored by various researchers. Rebars contribute in the strength of concrete by providing resistance

against punching deformation due to impact load. The behavior of GFRP rebars reinforced concrete in comparison to steel rebars reinforced concrete has been investigated for both full scale and prototype testing. Literature reported that strength parameters of GFRP rebars reinforced concrete and Steel rebars reinforced concrete came out to be more or less similar but GFRP rebars perform better in confinement of concrete than steel rebars. Also, the corrosion resistant property of GFRP rebars shows its dominance over steel rebars for selection as reinforcing rebars in concrete. Combination of GFRP rebars and short discrete fibres in concrete has been investigated by researchers, but addition of short discrete natural fibres along with GFRP rebars for strength enhancement needs to be investigated keeping in view the durability aspect of natural fibres.

II. MECHANISMS EMPLOYED FOR IMPACT LOADING

The impact testing of reinforced concrete along with analytical validation and FEM modeling has been done by various researchers. The percentage error gives the accuracy of analytical validation as well as predicts the probable actual scenario in case of impact loading. Syed et al. [3] investigated the performance of earthquake resistant reinforced concrete frame structure against blast explosions. A 14-story frame structure was modeled and analyzed against load combination incorporating the blast load. Blast load representing different amount of charge weights was defined using time-history and applied on dummy walls to reflect the effect produced by blast pressure. It was concluded that structural members of earthquake resistant structures have better blast resisting capacities as compared to those of non-earthquake resistant structures. A minimum of 6000 to 12000 mm standoff distance was found in the parametric study to avoid failure of a column. The longer span of a structural member is more susceptible in case of a blast load than a shorter span.

Luccioni et al. [4] analyzed the structural failure of a reinforced concrete building. AUTODYN software was used to model the building to investigate and compare the effects of blast on a real building. The processes from explosive charge detonation to blast wave propagation causing complete demolition was reproduced. An analysis-based location and magnitude was established for the explosion that was found to be accurate in reproducing the actual scenario by comparing the numerical results with the photographs. It was found that collapse occurred due to the failure of bottom story columns. The comparison of results justifies the use of simplified assumptions to analyze the structures for such type of events. The conducted analyzing approach was recommended for vulnerability assessment of structural configurations.
The experimental investigations on full scale and prototypes done by few researchers are presented here.

A. Full Scale Impact Testing of Reinforced Concrete

Syed et al. [5] investigated the influence of far-field and near-field blasts of 40000 mm and 2000 mm distance on reinforced concrete to study the damage behavior. It was found that blast pressure distribution and shock wave density significantly influence the failure mode of reinforced concrete panels. Higher shock wave density produces localized failures. Combinations of blast incident angle and shock wave density can be used to predict the behavior of reinforced concrete against near-field and far-field blast loading. Luccioni et al. [6] investigated the blast response of high strength concrete slab reinforced with steel fibres using contact explosion and elevated explosion. Hooked-end high carbon steel fibres of 0.7 mm diameter were added by 0.5% and 1% volume. The blast pressure time-histories were recorded. It was observed that greater fibre content changed the blast behavior by reducing the flexural cracks thickness, permanent deflections, area of damage and spalling.

Castedo et al. [7] performed blast load field testing on concrete slabs reinforced with steel and polypropylene fibres to investigate the impact resistance and validate the accuracy of results of finite element simulation results. Eight slabs were cast and tested at full scale out of which three reinforced concrete slabs were used for calibration of numerical model. Accelerometers and pressure transducers were used to compare the results with the calibration tests of numerical model. Using steel and polypropylene fibres in concrete enhanced the tensile strength of slabs against blast loading. The fibres absorbed the impact energy that lead to less damage in terms of cracking and overall failure. Pantelides et al. [8] conducted blast detonations on reinforced concrete panels and FRC panels. 1200 mm square panels of reinforced concrete, polypropylene fibre reinforced concrete (PPFRC), PPFRC with steel rebars, GFRP rebars reinforced concrete, and GFRP laminated reinforced concrete panel were tested against impact loading due to blast. The output of the testing was then categorized into medium, low and below antiterrorism standard protections. PPFRC panels with steel reinforcement performed better among all. Then monotonic static load tests were performed to investigate the post-blast load resistance capacity of panels. Coughlin et al. [9] performed the close-in blast testing using C-4 explosives on portable concrete barriers. Barriers reinforced with carbon fibres, nylon fibres and steel-synthetic blend were tested along with a control barrier having normal reinforced concrete. The condition of each barrier before and after blasts was photographed. Weight of each barrier was recorded before and after testing to evaluate the quantity of separated fragments in terms of weight. The results showed improvement in superficial damage and reduction of mass loss due to addition of nylon fibre 1.5% by volume as compared to normal concrete. It was observed that greater fibre surface area was able to hold the debris resulting in higher fragment size.

B. Prototype Impact Testing of Reinforced Concrete

Fig 1 shows simplified impact test setups based on kinetic energy, where a large mass with low velocity falls/strikes the specimen generating an impact. Fig 1 (a) shows the impact of an iron ball on a slab dropped from a certain height. Fig. 1 (b) shows the impact testing of a wall panel with a hammer using charpy's impact/ modified pendulum impact approach.

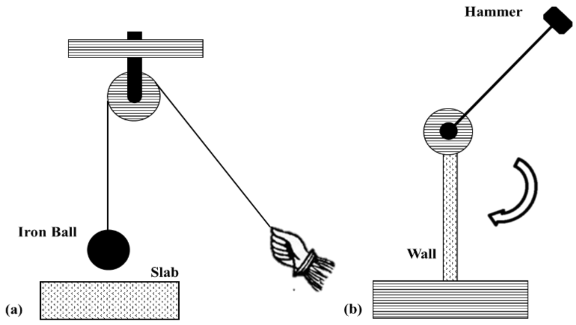

Fig 1: Simplified impact test setups by previous researchers; (a) Drop weight apparatus, (b) Pendulum type charpy's apparatus

Wang et al. [10] conducted a study on scaling down for investigating explosion resistance of reinforced concrete slab for close-in blast loading. Six number of one-way square concrete slabs with three scaled down factors were prepared and tested against blast load with the variation of two scaled distances. Damage levels investigated were spalling due to few cracks and moderate spalling. Macrostructural damage and fracture were found to be similar in all specimens but local damage was less in slabs having larger scaling factor as compared to the ones with smaller scaling factor. The results were analyzed and empirical equations were proposed to make the results coherent. Wang and Chouw [11] investigated the flexural behavior of coconut fibre reinforced concrete (CFRC) beams wrapped with two layers of flax fibre reinforced polymer (FFRP) under static and impact loading. An instrumented drop-weight apparatus was used to conduct impact tests. Three types of fibre content 1%, 3% and 5% by mass of cement were used. Analysis was done by obtaining flexural load, deflection, energy absorption and dynamic increase factor (DIF). The flexural strength of CFRC beams wrapped with FFRP was found to be three times greater than that of CFRC beams. Pham and Hao [12] investigated the axial impact resistance of concrete cylinders confined with varied number of carbon fibre reinforced polymer (CFRP) and GFRP layers. Drop-weight test set up was used to perform testing at different velocities of impact. Dynamic behavior was analyzed and it was observed that specimens experienced different extent of damage due to varying velocities. The cylinders wrapped with GFRP performed better against impact as compared to those of CFRP in terms of ductility and strength. Rupture strain of GFRP was higher than CFRP that shows better confinement of GFRP under impact loading.

Yu et al. [13] investigated the impact resistance of ultra-high-performance concrete (UHPC) reinforced with steel fibres using charpy's impact/modified pendulum impact apparatus. Steel fibres used were straight short, straight long and hooked. It was observed that in charpy's impact test, fibre length played a dominant role in improving the energy dissipation capacity of concrete. While in modified pendulum impact test the hybrid fibres were more beneficial in improving the energy dissipation capacity. Ramakrishna and Sundararajan [14] investigated the impact strength of few natural fibre reinforced cement mortar slabs using projectile impact test setups. Sisal, coir, jute, hibiscus cannebinus fibres were added in concrete with different fibre percentages (0.5-2) % and fibre length (20-40) mm to study the behavior of individual slab. It was found that fibre length and content has a direct relation with impact resistance. Greater the fibre length and percentage, higher will be the impact resistance. The trend of impact resistance showed that coir fibres significantly enhanced the impact resistance capacity followed by sisal, jute and hibiscus cannebinus fibres.

III. IMPACT RESISTANCE OF REINFORCED CONCRETE HAVING STEEL AND GFRP REBARS

Sadraie et al. [15] evaluated the dynamic performance of concrete slabs reinforced with steel and GFRP rebars using drop weight impact loading. Five steel rebars reinforced slabs and six GFRP rebars reinforced slabs of size1000 x 1000 x 75 mm were cast and tested. Parameters like crack development, failure mode, displacement-time, acceleration-time and strain-time responses were studied. A 105 kg cone frustum headed projectile was dropped from 2500 mm height. Slabs with GFRP rebars provided slightly less resistance and slightly high displacement than those having steel rebars. It was concluded that similar or better performance can be achieved using higher amount of GFRP rebars. Goldston et al. [16] investigated the performance of GFRP rebars reinforced concrete beams against impact loading. Six beams having length of 2400 mm and cross-section of 150 x 100 mm were tested using a drop hammer machine. 110 kg hammer was dropped from a height of 1200 mm. Shear plug type failure was observed around the impact zone. Average dynamic amplification factor was calculated to be 1.15, which shows the higher dynamic moment capacity of concrete. It was observed that at first contact, resistive property of GFRP rebars reinforced concrete was controlled by inertia forces until the flexural strength starts contributing against impact load.

Ahmed et al. [17] conducted the full-scale pendulum impact field testing of 11000 mm long prototype bridge concrete barriers and laboratory testing of 2600 mm long prototype concrete barriers reinforced with Steel and GFRP rebars. Reinforcement amount of steel and GFRP was kept same to compare the results. The failure load capacity of both steel and GFRP reinforced barriers turned out to be same but the reinforcement strains after failure were higher in GFRP reinforced prototype than those of steel. Garfield at al. [18] investigated the performance of reinforced concrete and synthetic-fibre reinforced concrete wall panels having mild steel and GFRP rebars against blast loading. Varying parameters were the wall thickness and the charge weight of the blast. Strain gauges, accelerometers and pressure transducers were used to record data. Analysis of data showed that out of all panels, the FRC panel with steel reinforcement performed better as compared to others.

Razaqpur et al. [19] performed blast load testing on reinforced concrete panels having externally bonded GFRP laminates. GFRP rebars mesh was provided around the panel as reinforcement laminates. A 3000 mm standoff detonation of 22.4kg and 33.4 kg explosives was performed. Characteristics of blast wave i.e. incident and reflective pressures and impulses, central deflection, strain in steel and concrete surface were measured. Damage assessment was done to study the post blast failure and residual strength of panels having incomplete damage was investigated. It was observed that GFRP laminated panels performed better as compared to control panels. The standoff distance and weight of charge significantly effects the level of damage to reinforced concrete. El-Salakawy et al. [20] performed full scale pendulum impact testing of bridge barriers reinforced with GFRP rebars. Eight barriers having height of 10000 mm and connected with slab bolted in ground, were tested using pendulum strike of a 3-ton iron ball. The damage was evaluated in terms of cracking pattern, crack width and strain rate. It was observed that the wall-slab joint successfully transferred impact load without showing any failure.

Table 1 shows testing details and output dominance of experimental investigations on concrete reinforced with steel rebars and GFRP rebars by previous researchers. It is evident from literature that GFRP rebars perform nearly similar to steel rebars in terms of strength, cracking behavior and resistance against impact loading.

Table 1: Summarized details on impact resistance of steel and GFRP rebars reinforced concrete in previous researches

Reference	Impact mechanism	Impact weight	Prototype specifications	Outcome dominance
Sadraie et al. (2019)	Drop weight cone frustum headed projectile	105 kg	1000 x 1000 x 75 mm - slabs	Steel performed slightly better than GFRP in terms of resistance and displacement of concrete.
Goldston et al. (2016)	Drop weight hammer	110 kg	2400 x 150 x 100 mm - beams	Dynamic amplification factor showed higher dynamic moment capacity of concrete.
Ahmed et al. (2013)	Pendulum impact	1750 kg	2600 mm long bridge barriers	Similar behavior for both steel and GFRP reinforced concrete was observed.
Garfield at al. (2011)	Charge detonation	6.1 & 12.8 kg	1200 x 1200 mm - wall panels	Steel rebar reinforced wall and GFRP overlay reinforced wall performed better.
Razaqpur et al. (2007)	Charge detonation	22.4 & 33.4 kg	1000 x 1000 x 700 mm - slabs	GFRP retrofitted slabs performed better as compared to control slabs.
El-Salakawy et al. (2004)	Pendulum impact	3.0 ton	10000 mm long bridge barriers	Similar behavior for both steel and GFRP reinforced concrete in terms of cracking, energy absorption and strength.

IV. IMPACT RESISTANCE OF SHORT DISCRETE FIBRE REINFORCED CONCRETE

Hussain and Ali [21] investigated the impact resistance of jute fibre reinforced concrete (JFRC) using simplified drop weight apparatus. 1.5 kg impact weight was dropped from 600mm and 900mm heights. Small slab panels of size 430 x 280 x 75 mm of plain concrete (PC) and JFRC were tested and number of blows were evaluated till failure. Analysis showed that impact resistance of JFRC was 6 times greater than that of PC. It was concluded that addition of short jute fibres reduced the steel reinforcement ratio up to 28%. Mastali et al. [22] investigated the impact resistance of reinforced self-compacting concrete having recycled GFRP. Specimens with different volume fractions were tested using drop weight apparatus and scanning electron microscope (SEM) analysis was performed to study the failure mechanism of fibres in the matrix. Impact resistance was calculated on the basis of number of blows till first crack failure and ultimate crack failure. It was concluded that greater fibre content results in higher impact resistance.

Nili and Afroughsabet [23] examined the impact resistance of concrete having silica fumes and 12 mm long polypropylene fibres in four volume fractions of 0%, 0.2%, 0.3% and 0.5%. Concrete mixtures were prepared using 0.36 and 0.46 water cement ratios. 150 x 64 mm disks were tested with a 4.45 kg hammer in a drop weight impact apparatus. It was observed that using 0.5% polypropylene fibres with silica fumes, improves the performance of concrete in terms of impact resistance. Yamaguchi et al. [24] performed contact detonation on polyethylene fibre reinforced concrete (PEFRC) slabs. 13 slabs of 600 x 600 mm dimensions were prepared having 50 mm and 100 mm thickness out of which 9 were reinforced with 30 mm long polyethylene fibres. Explosives weighing 100g and 200g were used with an electric detonator. The tested specimens were analyzed in terms of diameter and depth of crater and spall. It was found that PEFRC was effective in reducing the spalling damage and fragments launch. Equation for estimating the depth of damage was derived for PEFRC slabs against contact detonation. Mohammadi et al. [25] investigated the impact resistance of concrete beams reinforced with steel fibres. Drop weight hammer apparatus was used to count the number of blows till visibility of first crack and ultimate failure. Steel fibres were added with three volume fractions i.e. 1%, 1.5% and 2% with mixed steel fibres of sizes 0.6 x 2 x 25mm and 0.6 x 2 x 50mm. The concrete having 2% volume fraction of 100% long fibres gave highest impact resistance among all. Nataraja et al. [26] investigated the statistical variation in impact resistance of concrete having steel fibres using drop weight test. Results showed that there was large variation in the impact resistance values of both steel fibre reinforced concrete (SFRC) and PC. Large number of samples were recommended to have distribution of impact results in order to draw reliable conclusions.

Ong et al. [27] performed instrumented projectile impact test to investigate the impact resistance of fibre concrete slabs. Fibre type and volume fraction were taken as variables for 0%, 1% and 2% of polyvinyl alcohol, polyolefin and steel fibres. 10 square slabs of 1000 x 1000 mm cross-section and 50 mm thickness were tested by dropping 43 kg projectile mass. It was observed that slabs having hooked-end fibres of steel performed better in terms of energy absorption and cracking as compared to the slabs of other two fibre types. Among the other two, slabs having polyvinyl alcohol fibres gave higher fracture energy values than those of polyolefin fibres.
Table 2 shows the impact testing details and conclusions drawn by various researchers. The literature suggests that fibres can influence the behavior of concrete when added in optimum percentages. The percentage of fibres to be added also depends upon the fibre characteristics that may or may not be suitable in a concrete matrix.

Table 2: Summarized details on impact resistance of short discrete fibre reinforced concrete in previous researches

Reference	Impact mechanism	Impact weight	Prototype specifications	Conclusions
Hussain and Ali (2019)	Drop-weight apparatus	1.5 kg	430 x 280 x 75 mm – Slab panels	Impact resistance of JFRC was 6 times greater than that of PC.
Mastali et al. (2016)	Drop-weight apparatus	4.45 kg	150 x 65 mm - Disks	Addition of recycled GFRP fibres improved the mechanical properties and impact strength of concrete.
Nili and Afroughsabet (2010)	Drop-weight apparatus	4.45 kg	150 x 64 mm - Disks	0.5% Polypropylene fibres along with silica fumes enhances the impact resistance of concrete.
Yamaguchi et al. (2011)	Contact detonation	100 & 200 g	600 x 600 mm - Slabs	PEFRC was effective in reducing the spalling damage and fragments launch.
Mohammadi et al. (2009)	Drop-weight apparatus	5.54 kg	500 x 100 x 100 mm – Beams	Specimens having 2 % volume fraction of steel fibres performed better as compared to 1.5% and 1%.
Nataraja et al. (1999)	Drop-weight apparatus	-	300 x 150 mm –Cylinders	Due to large variation in impact resistance values of SFRC cylinders, greater sample size was recommended.
Ong et al. (1999)	Instrumented projectile impact	43 kg	1000 x 1000 x 50 mm - Slabs	Slabs reinforced with steel fibres performed better than those having polyolefin and polyvinyl alcohol fibres.

V. CONCLUSIONS

Impact resistance investigation using state of the art equipment gives output at a higher accuracy level as compared to simplified testing. The behavior of concrete against impact loading can be predicted better by conducting full scale blast testing in field as well as laboratories. Their analytical validation can be used to develop empirical relations in order to perform simplified testing with the identification of error percentages. GFRP rebars as replacement of steel gives more or less same results with the advantage of GFRP rebars being light weight and corrosion resistant. Literature supports the inclusion of artificial fibres in improving the impact resistance of concrete. Use of natural fibres in optimum percentage can play a vital role in enhancement of impact strength of concrete.

VI. RECOMMENDATIONS

Empirical relations to support simplified testing and to bridge the gap between actual scenarios and prototype testing needs to be explored in detail. Instrumentation of test setups to get accuracy for results is an important aspect to be covered in researches. Post-impact durability of natural fibres in concrete requires an elongated research program to investigate whether natural fibre reinforced concrete can sustain enough strength to be applicable in real life. The aspects regarding the combination of natural fibres and GFRP rebars in concrete needs to be investigated to have a better understanding of their collective behavior for implementation in construction industry.

VII. ACKNOWLEDGEMENTS

The authors would like to acknowledge CUST library facility for providing relevant literature that helped a lot in smooth conduct of this study.

REFERENCES

[1]. ACI 544.2R-89: Measurement of properties of fiber reinforced concrete.

[2]. J. Kim, K. Wille, S. El-Tawil, and A. E. Naaman, "Testing of cementitious materials under high-strain-rate tensile loading using elastic strain energy," *Journal of Engineering Mechanics*, vol. 137, no. 4, pp. 268-275, April 2011.

[3]. Z. I. Syed, O. A. Mohamed, K. Murad, and M. Kewalramani, Performance of earthquake-resistant RCC frame structures under blast explosions. *Procedia Engineering*, vol. 180, pp. 82-90, Jan. 2017.

[4]. B. M. Luccioni, R. D. Ambrosini, and R. F. Danesi, "Analysis of building collapse under blast loads," *Engineering structures*, vol. 26, no. 1, pp. 63-71, Jan 2004.

[5]. Z.I. Syed, S.N. Raman, T. Ngo, P. Mendis, and T. Pham, "The failure behaviour of reinforced concrete panels under farfield and near-field blast effects," *In Structures*, vol. 14, pp. 220-229, June 2018.

[6]. B. Luccioni, F. Isla, R. Codina, D. Ambrosini, R. Zerbino, G. Giaccio, and M. C. Torrijos, "Effect of steel fibers on static and blast response of high strength concrete," *International Journal of Impact Engineering*, vol. 107, pp. 23-37, Sep. 2017.

[7]. R. Castedo, P. Segarra, A. Alañon, L. M. Lopez, A. P. Santos, and J. A. Sanchidrian, "Air blast resistance of full-scale slabs with different compositions: Numerical modeling and field validation," *International Journal of Impact Engineering*, vol. 86, pp. 145-156, Dec. 2015.

[8]. P. Pantelides, T. T. Garfield, W. D. Richins, T. K. Larson, and J. E. Blakeley, "Reinforced concrete and fiber reinforced concrete panels subjected to blast detonations and post-blast static tests," *Engineering structures*, vol. 76, pp. 24-33, Oct. 2014.

A. M. Coughlin, E. S. Musselman, A. J. Schokker, and D. G. Linzell, "Behavior of portable fiber reinforced concrete vehicle barriers subject to blasts from contact charges," *International Journal of Impact Engineering*, vol. 37, no. 5, pp. 521-529, May 2010.

[9]. W. Wang, D. Zhang, F. Lu, S. C. Wang, and F. Tang, "Experimental study on scaling the explosion resistance of a one-way square reinforced concrete slab under a close-in blast loading," *International Journal of Impact Engineering*, vol. 49, pp. 158-164, Nov 2012.

[10]. W. Wang, and N. Chouw, "Flexural behaviour of FFRP wrapped CFRC beams under static and impact loadings," *International Journal of Impact Engineering*, vol.111, pp. 46-54, Jan. 2018.

[11]. T. M. Pham, and H. Hao, "Axial impact resistance of FRP-confined concrete," *Journal of Composites for Construction*, vol. 21, no. 2, pp. 04016088, April 2017.

[12]. R. Yu, L. Van Beers, P. Spiesz, and H. J. H. Brouwers, "Impact resistance of a sustainable Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) under pendulum impact loadings," *Construction and Building Materials*, vol. 107, pp. 203-215, Mar. 2016.

[13]. G. Ramakrishna, and T. Sundararajan, "Impact strength of a few natural fibre reinforced cement mortar slabs: a comparative study," *Cement and concrete composites*, vol. 27, no. 5, pp. 547-553, May 2005.

[14]. H. Sadraie, A. Khaloo, and H. Soltani, "Dynamic performance of concrete slabs reinforced with steel and GFRP bars under impact loading," *Engineering Structures*, vol. 191, pp. 62-81, Jul 2019.

[15]. M. Goldston, A. Remennikov, and M. N. Sheikh, "Experimental investigation of the behaviour of concrete beams reinforced with GFRP bars under static and impact loading," *Engineering Structures*, vol. 113, pp. 220-232, Apr 2016.

[16]. A. Ahmed, C. Dulude, and B. Benmokrane, "Concrete bridge barriers reinforced with glass fibre-reinforced polymer: static tests and pendulum impacts," *Canadian Journal of Civil Engineering*, vol. 40, no. 11, pp. 1050-1059, Jul 2013.

[17]. T. T. Garfield, W. D. Richins, T. K. Larson, C. P. Pantelides, and J. E. Blakeley, "Performance of RC and FRC wall panels reinforced with mild steel and GFRP composites in blast events," *Procedia Engineering*, 10, 3534-3539, Jan. 2011.

A. G. Razaqpur, A. Tolba, and E. Contestabile, "Blast loading response of reinforced concrete panels reinforced with externally bonded GFRP laminates," *Composites Part B: Engineering*, vol. 38, no. 5-6, pp. 535-546, July 2007.

[18]. El-Salakawy, R. Masmoudi, B. Benmokrane, F. Brière, and G. Desgagné, "Pendulum impacts into concrete bridge barriers reinforced with glass fibre reinforced polymer composite bars," *Canadian Journal of Civil Engineering*, vol. 31, no. 4, pp. 539-552, Aug. 2004.

[19]. T. Hussain, and M. Ali, "Improving the impact resistance and dynamic properties of jute fiber reinforced concrete for rebars design by considering tension zone of FRC," *Construction and Building Materials*, vol. 213, pp. 592-607, July 2019.

[20]. M. Mastali, A. Dalvand, and A. R. Sattarifard, "The impact resistance and mechanical properties of reinforced self-compacting concrete with recycled glass fibre reinforced polymers," *Journal of Cleaner Production*, vol. 124, pp. 312-324, June 2016.

[21]. M. Nili, and V. Afroughsabet, "The effects of silica fume and polypropylene fibers on the impact resistance and mechanical properties of concrete," *Construction and Building Materials*, vol. 24, no. 6, pp. 927-933, Jun 2010.

[22]. M. Yamaguchi, K. Murakami, K. Takeda, and Y. Mitsui, "Blast resistance of polyethylene fiber reinforced concrete to contact detonation," *Journal of Advanced Concrete Technology*, vol. 9, no. 1, pp. 63-71, Feb 2011.

[23]. Y. Mohammadi, R. Carkon-Azad, S. P. Singh, and S. K. Kaushik, "Impact resistance of steel fibrous concrete containing fibres of mixed aspect ratio," *Construction and Building Materials*, vol. 23, no. 1, pp. 183-189, Jan 2009.

[24]. M. C. Nataraja, N. Dhang, and A. P. Gupta, "Statistical variations in impact resistance of steel fiber-reinforced concrete subjected to drop weight test," *Cement and Concrete Research*, vol. 29, no. 7, pp. 989-995, July 1999.

[25]. K. C. G. Ong, M. Basheerkhan, and P. Paramasivam, "Resistance of fibre concrete slabs to low velocity projectile impact," *Cement and Concrete Composites*, vol. 21, no. 5-6, pp. 391-401, Dec 1999.