Magazine of Civil Engineering. 2021. 106(6). Article No. 10604

Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

DOI: 10.34910/MCE.106.4

Behavior of composite steel plate-sustainable concrete slabs under impact loading

H. Suwaid, K. Aziz , S. Hama*

Department of Civil Engineering, College of Engineering, University of Anbar, Ramadi, Iraq

**E-mail: drsheelan@uoanbar.edu.iq*

Keywords: composite steel plate-concrete slab, degree of interaction, deflection, impact loading, sustainable concrete, waste plastic fiber

Abstract. Concrete has been used as a protective structure to resist impact and blast loads for many years. Recently, researchers have been developing various strengthening methods to increase the impact resistance of concrete. The study includes, first, investigating the basic properties of normal concrete with plastic fibers such as compressive strength and flexural strength, and, secondly, a research of the low-velocity impact resistance of high-performance concrete with steel fiber specimens using a falling mass dropped from the same heights. The impact test used 500×500×60 mm slabs made of plain concrete with different volume fractions of plastic fiber. Test results indicated that incorporating plastic fibers in concrete significantly improves its impact resistance. There is a marginal increase in energy absorption for a change in fiber content from 0.5 to 0.75 %. The authors also considered other parameters besides waste plastic fiber percentages, e.g. degree of interaction (DOI), the method of fixing the stud to a steel plate (welding and epoxy), and the type of structure (composite and non-composite). A theoretical analysis revealed a difference between theoretical and experimental results due to repetitive strikes in the experimental test resulting in accumulated residual deflections.

1. Introduction

Composite structures are the structures made of two or more materials linked together by shear connectors. Steel-concrete composite structures are most common in construction field. Petkevicius and Valivonis investigated the effect of steel fiber on composite steel-concrete slabs under static short-time load. They found that the slip in the composite slabs incorporating steel fiber began at ~50–60 % higher load than in the slabs free of steel fiber [1]. Roesler et al. investigated the response of synthetic fiber-reinforced concrete slabs under monotonic loading. The results showed that 0.32 and 0.48 % of fiber increased the flexural cracking load of concrete slabs under center load by 25 and 32 %, respectively, compared to the one without fibers [2]. David et al. studied the effected of hooked end steel fiber on the redistribution of crack pattern and load-carrying capacity of two-way simply supported slabs. They found that concrete slabs contain steel fibers reinforced showed more cracks development with smaller crack widths compared to conventional slabs without fibers which means a more ductile behavior [3]. Due to the increased global interest in environment issues and waste recycling, many researchers focus on the reuse of waste material in concrete and the study of the influence these wastes exert on the properties of such concrete. Plastic fiber from PET bottles is an example of a waste used widely in concrete. Another study showed that adding plastic aggregate improved impact resistance of concrete [4]. Aziz et al. showed that plastic fibers increased the slip between concrete and steel section in push-out test [5]. Marthong and Sarma (2016) investigated the effects of the geometry of PET fibers on shrinkage cracking of cement–based composites [6]. Fibers of different geometry were under study: straight, deformed, flattened end and crimped end. They found that deformed fibers improved the anchorage effect and performed better in restraining the deformation in concrete. Hama (2017) incorporated plastic fibers in

Suwaid, H., Aziz, K., Hama, S. Behavior of composite steel plate- sustainable concrete slabs under impact loading. Magazine of Civil Engineering. 2021. 106(6). Article No. 10604. DOI: 10.34910/MCE.106.4

order to improve the porcelinate lightweight concrete strengths. She found that 0.75 % of plastic fiber compared to reference mix gave the highest compressive strength, while 1 % plastic fiber gave the flexural strength [7]. In addition, there are many researches on the effect of plastic fiber on concrete properties. However, the effect of this fiber on structural behavior of structural sections such as beams, slabs, columns etc. is limited. Moreover, there are several studies about the effect of plastic fiber on mechanical properties of concrete.

Zineddina and Krauthammer (2007) investigated the behavior of two-way slabs under impact loads. Tests results indicated that a slab and its failure modes are affected by the amount and details of steel reinforcement, impact load and drop height [8]. Tahmasebinia and Remennikov (2008) found that finite element analysis is capable of making reasonable estimations available in order to determine the possible failure modes of reinforced concrete slabs subjected to impact loads. The quantity of mesh density and direction of the sub-division on the surface of a concrete slab, where it may follow the trajectory of cracking, can play an important role in finite element analysis simulation [9]. Trevor and Vecchio (2014) investigated the behavior of steel fibers reinforced concrete slabs (SFRCS) under high mass, low-velocity impact loading conditions. Local damage development was found to be of less significance in the SFRCS. The slabs with ρ = 0.00420 and ρ = 0.00592 exhibited similar performance characteristics in terms of strength, stiffness, and local damage development [10]. Margareth and Matheus (2015) studied the effect of plastic fibers on energy absorption capacity. The result indicates an increase of up to 76 % in the energy absorption capacity of PFRC with 2.0 % fiber. In addition, it has been shown that the inclusion of recycled concrete is advantageous from energy point of view as it keeps the interior temperature remains lower, when the outside temperature rises, as compared to the conventional concrete. Hama investigated the effects of PET plastic aggregate on the impact resistance of concrete. The tests result indicated that adding of plastic aggregate improved impact resistance of slabs; energy capacity absorption also increased due to adding waste plastic [11]. Xiao et al. [12] tested six slabs under low-velocity impact. The results from high loading rate and impact tests were compared. The tests results indicate similar damage process, failure mode, strain rate, and energy absorption capacity, which suggests the possibility of using high load rate test to help understand slab's performance under low-velocity impact [12]. Manfred et al. studied how deformable projectiles impact reinforced concrete slabs at velocities of up to 400 m/sec. It was found that the penetration depths were smaller than those corresponding to undeformable projectiles impact, and the difference increased with the increase in velocity [13]. Al-Hadithi used styrene butadiene rubber SBR with different weight ratios of polymer to cement (3 %, 5 %, and 10 %) to improve of impact resistance of concrete. The improvements were significant in low-velocity impact resistance. The maximum increases were (33.33 %, 75 %, and 83.33 %) at ultimate failure for falling mass heights of 2400 mm, 1200 mm and 830 mm respectively. The polymer modified concrete beams have a stiffer response in terms of structural behavior, more ductility and lower cracking deflection than those of the reference concrete [14].

From literature review, one can see there is no study about the effect of plastic fiber on impact resistance of composite steel plate-concrete slabs. Therefore, this study aims to provide the necessary data in this field.

The objective of the present study is to demonstrate the effect of plastic fiber content on the behavior of composite steel plate-concrete slabs. This study deals with normal concrete with plastic fibers to assess its utility as construction materials for civilian structures.

2. Methods

2.1. Material, Mix Proportions and Specimens Tests

We used ordinary Portland cement (Type I) complying with Iraqi specification No. 5 / 1984 [15]. As the fine aggregate, we used natural sand that complied with the requirements of the Iraqi specification No. 45 / 1984. It has 2.6 specific gravity, 0.42 % sulfate content, 0.75 % absorption and 2.8 fine modulus. The crushed stone we used as the coarse aggregate had the maximum size of 12.5 mm meeting the requirements of Iraqi specification No. 45 / 1984 [16]. It has 2.6 specific gravity, 0.09 % sulfate content, and 0.52 % absorption. The waste plastic considered in this study is soft drink bottles waste plastics. We employed a shredder machine to slice the waste plastic bottles in uniform shapes with an average length of 35 mm, width of 4 mm and aspect ratio of 28. The materials were mixed in a rotating pan in accordance with ASTM C192-02 [17]. Compressive strength test was made according to ASTM C39-03 [18] for cylinder specimens (300×150 mm). We tested three specimens for each type of mixes and took the average value. Flexural strength of concrete was measured on 100×100×400 mm prism specimens in conformity with ASTM C293-03 [19]. We tested three prisms for each type of mixes and tool the average value.

2.2. Impact Test

As reported by the ACI Committee 544, a drop-weight test assessed the resistance of concrete under dynamic loadings [20]. The low velocity impact test was conducted using a 4 kg steel ball dropping freely from the height of 2.4 m. Twenty-two 500×500×60 mm composite slabs consisting of BRC reinforced concrete slabs resting on top of a hot rolled steel plate with the same dimensions and 3 mm thickness were tested under impact force. Shear stud connectors were used to ensure the composite action between concrete slab and steel plate. The composite slab was designed based on the full interaction theory. The composite slab details are clarified in Fig. 1. Two dial gauge recorders on average were placed under the steel plate to measure the central deflection (see Fig. 2). The properties of stud connection are listed in Table 1.

Table 1. Geometry and mechanical properties of stud shear connector.

Diameter (mm)	Height (mm)	Yielding stress (MPa)	Ultimate strength (MPa)	% Elongation
6	35	612	780	20.1

Slabs were placed in their position in the testing frame. The falling mass of 3 kg was then dropped repeatedly and the number of blows required to cause first crack was recorded. The number of blows required for failure (no rebound) was also recorded. The number and details of slabs, which were used in this test, are presented in Table 2.

Three parametric studies taken:

- Degree of interaction (D.O.I.) (0, 50, 100 %)
- Percentages of plastic fibers (0, 0.5, 0.75, 1 %)
- Type of connection between steel plate and stud shear connector (welding, epoxy).

Table 2. Composite slabs details.

No.	Symbol	% WPF	% Degree of interaction	Type of connection
	S1	0	50	Epoxy glued studs
	S2	0	No studs	Epoxy glued plate without studs
	S3	0	0	Welding
	S4	0	50	Welding
	S5	0	100	Welding
	S6	0	0	Control without plate with 74 mm RC slab only
	S7	0.5	50	Epoxy glued studs
	S8	0.5	No studs	Epoxy glued plate without studs
	S9	0.5	0	Welding
	S10	0.5	50	Welding
	S11	0.5	100	Welding
	S12	0.75	50	Epoxy glued studs
	S13	0.75	100	Epoxy glued studs
	S14	0.75	No studs	Epoxy glued plate without studs
	S15	0.75	0	Welding
	S16	0.75	50	Welding
	S17	0.75	100	Welding
	S18	1	50	Epoxy glued studs
	S19	1	No studs	Epoxy glued plate without studs
	S20	1	0	Welding
	S21	1	50	Welding
	S22	1	100	Welding
	S23	2	50	Welding

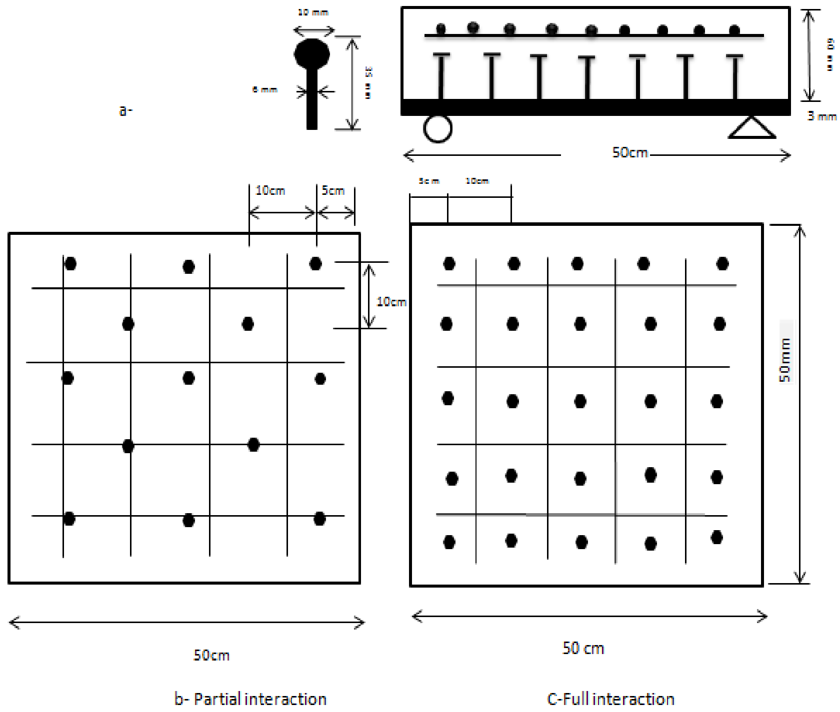

**Figure 1. Details of composite slabs a) Front view;
b) Top view of 50 % I.O.D slab; c) Top view of 100 % I.O.D slab.**

Figure 2. Frame test for impact loading.

3. Results and Discussions

3.1. Compressive and Flexural Strengths

Compared with the control specimen, higher contain of WPF (waste plastic fibers) increased the compressive strength of the slabs up to the point of 0.75 % WPF as shown in Fig. 3. There is a drop in values bellow that for the control specimen, when the WPF percentage was equal to 1 % as shown in Table 2. Flexural strength increased along with the % WPF (see Fig. 4) due to an enhancement in tensile strength of concrete. The presence of WPF made tight microscopic cracks propagate and reinforce the concrete matrix. Addition of WPF assists in converting the brittle properties of concrete to ductile ones [4, 7].

Table 2. Test results for compressive strength.

Age (Days)	%WPF	Compressive strength – (MPa)	% change	Flexural strength (MPa)	% change
14	0.00	17.8	–	2.55	–
	0.50	18.7	+5	2.69	+5.5
	0.75	19.2	+7.9	2.77	+8.6
	1.00	16	–10.1	2.78	+9
28	0.00	22.5	–	2.88	–
	0.50	23.2	+3.1	3.1	+7.6
	0.75	23.7	+5.3	3.19	+10.8
	1.00	19.8	–12	3.26	+13.2
56	0.00	25.8	–	3.09	–
	0.50	26.4	+2.3	3.34	+8.1
	0.75	26.9	+4.3	3.44	+11.3
	1.00	22.5	–12.8	3.52	+13.9

(+) increase
(–) decrease

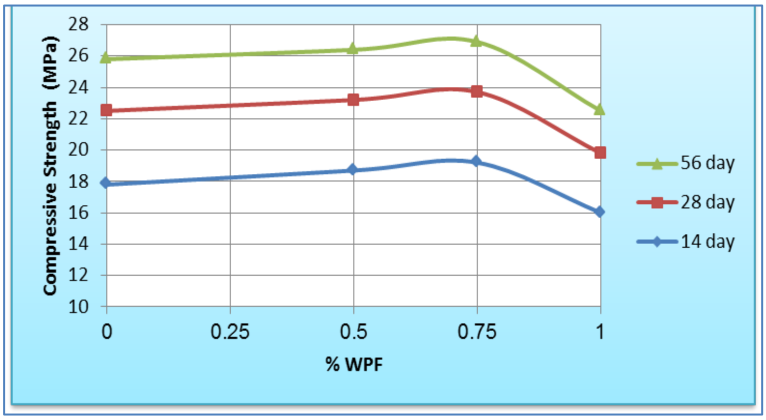

Figure 3. Dependence of compressive strength on % WPF for different ages.

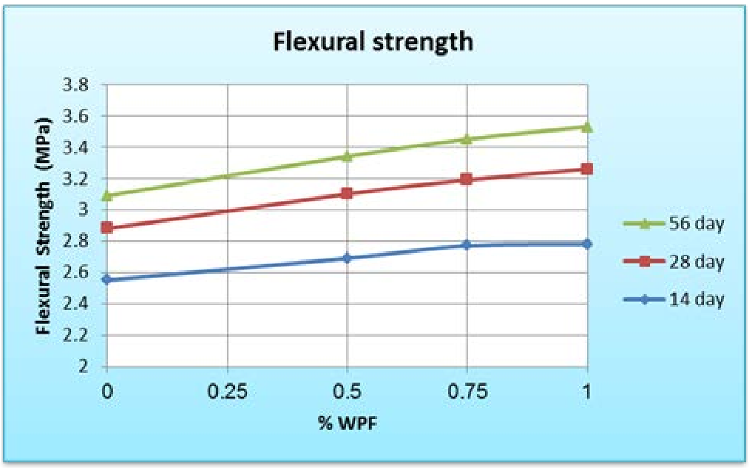

Figure 4. Dependence of Flexural strength on % WPF for different ages.

3.2. Impact test results

The number of blows that cause first crack and then failure (smashing of reinforced concrete slab), and deflection due to first blow are recorded for all composite slabs. Fig. 5 shows slabs before and after failure. The following results were recorded according to the parametric study adopted in this research:

Slabs before test **Sabs after test**

Figure 5. Failure of composite slabs under Impact force.

3.2.1 Effects of waste plastic fibers (WPF)

With WPF percentages growing, the number of blows causing the first crack increases regardless of the degree of interaction between concrete slab and steel plate. However, both the number of blows at failure and maximum deflection at failure experience a drop and a rise respectively for WPF of 0.75 % and higher (see Fig. 6–8).

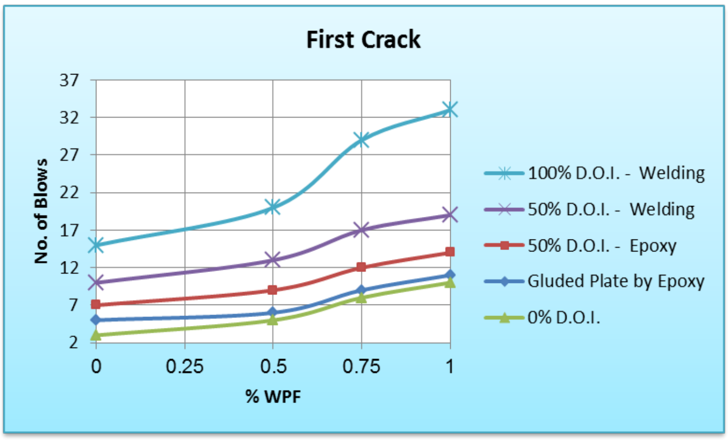

Figure 6. No. of blows at first crack dependence of the number of blows on % WPF.

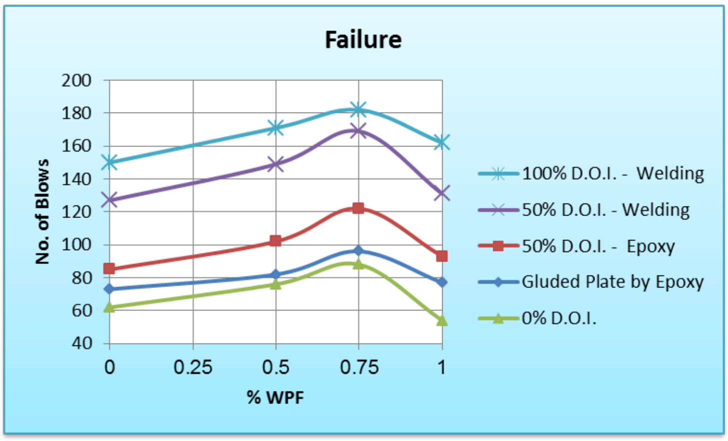

Figure 7. No. of blows at failure dependence of the number of blows on % WPF.

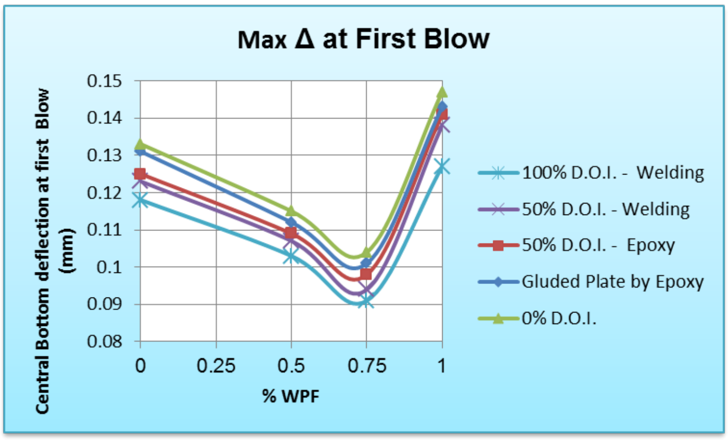

Figure 8. Deflection at failure dependence of max. deflection on % WPF.

A relatively low content of plastic fibers effectively enhances the capacity of composite slabs and makes the structural response more ductile; volume fractions of plastic fibers higher than 1.0 % slightly improve the number of blows at failure, but remarkably enhance the composite slabs ductility.

3.2.2 Effects of degree of interaction

Test results shown in Fig. 9–11, indicate that the number of blows required to reach the first crack and failure (except max. deflection at failure) are increasing along the degree of interaction in comparison with 0 % D.O.I. This explained by the fact that the composite slab strength capacity increases against the applied loading due to the increase in rigidity and stiffness. In addition, the presence of steel plate makes the composite slab more ductile.

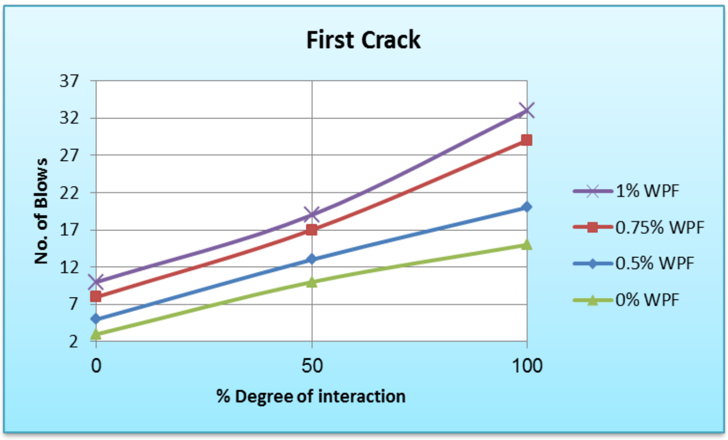

Figure 9. No. of blows at first crack dependence of the number of blows on D.O.I

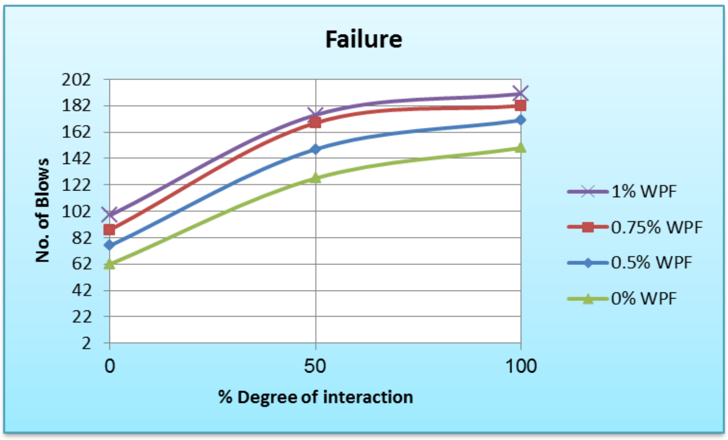

Figure 10. No. of blows at failure dependence of the number of blows on D.O.I.

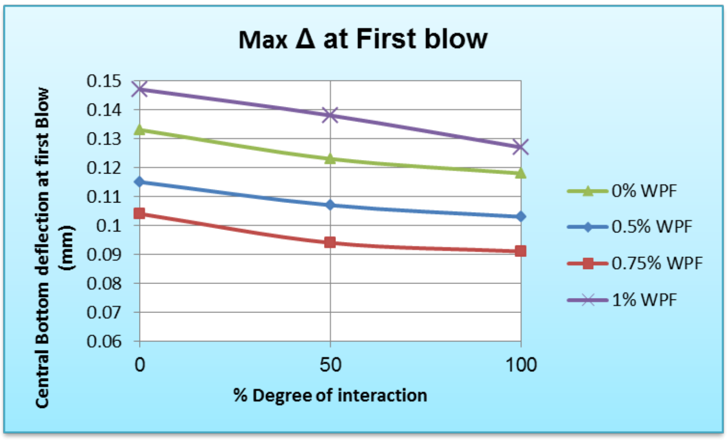

Figure 11. Deflection at failure dependence of max. deflection on D.O.I.

3.2.3 Methods of fixing stud connectors on steel plate (welding and epoxy)

Two methods were adopted to connect the stud connectors and steel plate: welding and epoxy resin.

The number of blows at the first crack and at failure stage is less for epoxy glue compared with welding for the same ratio of WPF and identical D.O.I. (see Fig. 12, 13). Moreover, the maximum deflection increases in case of using epoxy compared to welding for the same WPF % and D.O.I. (see Fig. 14). The strength resistance and capacity of welding are greater than those of epoxy.

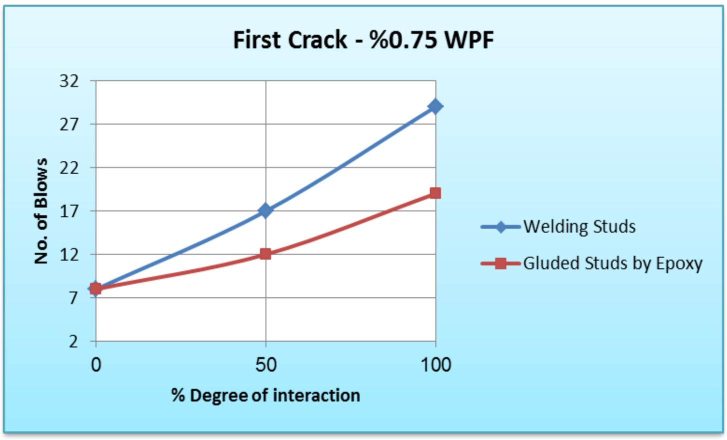

Figure 12. No. of blows vs. D.O.I. for epoxy glue and welding at first crack.

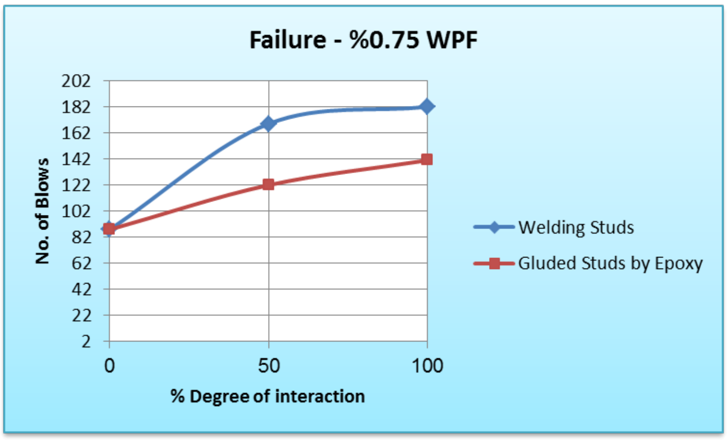

Figure 13. No. of blows vs. D.O.I. for epoxy glue and welding at failure.

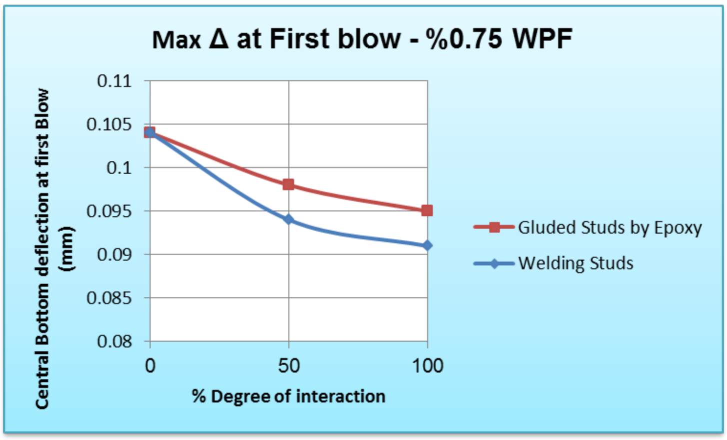

Figure 14. Maximum deflection vs. D.O.I. for epoxy glue and welding at failure.

3.3. Energy Absorption Capacity

Energy absorption capacity by can be calculated from the number of total blows that caused the failure as following:

$$\text{Impact energy capacity} = \text{Number of blows* Mass of iron ball (4 kg)} \times \times 9.8\ \text{m/s}^2 \times \text{Drop distance (2.4 m)} \quad (1)$$

The results are listed in Table 3 as following.

Table 3. Impact energy capacity.

Symbol	% WPF	% Degree of interaction	Type of connection	Number of blows up to failure	Impact energy capacity, J
S1	0	50	Epoxy glued studs	85	7996.80
S2	0	No studs	Epoxy glued plate without studs	73	6867.84
S3	0	0	Welding	62	5832.96
S4	0	50	Welding	127	11948.16
S5	0	100	Welding	150	14112.00
S6	0	0	Control without plate with 74 mm RC slab only	16	1505.28
S7	0.5	50	Epoxy glued studs	90	8467.20
S8	0.5	No studs	Epoxy glued plate without studs	82	7714.56
S9	0.5	0	Welding	76	7150.08
S10	0.5	50	Welding	149	14017.92
S11	0.5	100	Welding	171	16087.68
S12	0.75	50	Epoxy glued studs	122	11477.76
S13	0.75	100	Epoxy glued studs	141	13265.28
S14	0.75	No studs	Epoxy glued plate without studs	98	9219.84
S15	0.75	0	Welding	88	8279.04
S16	0.75	50	Welding	169	15899.52
S17	0.75	100	Welding	182	17122.56
S18	1	50	Epoxy glued studs	93	8749.44
S19	1	No studs	Epoxy glued plate without studs	77	7244.16
S20	1	0	Welding	54	5080.32
S21	1	50	Welding	131	12324.48
S22	1	100	Welding	162	15240.96
S23	2	50	Welding	81	7620.48

3.3.1 Effects of waste plastic fibers (WPF)

As WPF percentage rises, the number of blows required to reach the first crack increases regardless of degree of interaction between concrete slab and steel plate, which led to an increase in strain energy capacity of slabs. For example, for a group of slabs with 50 % D.O.I and welding connection between studs and steel plate, the reference slab without plastic fibers had a strain energy capacity of 11948.16 J, while the strain energy for 0.5 %, 0.75 %, 1 % and 2 % WPF were 14017.92, 15899.52, 12324.48 and 7620.48 J, respectively. One can observe that all WPF percentage up to 1 % increased the energy capacity of composite slabs compared to the reference one. However, the slab with 2 % WPF content had a decreased energy capacity absorption compared to the reference one.

3.3.2 Effects of degree of interaction

Test results shown in Table 3 indicate that the energy capacity is increasing along with degree of interaction compared with 0 % D.O.I. For example, the slab of 0 % D.O.I. and 0 % WPF had strain energy capacity of 5832.96 J, while the slabs of 50 % and 100 % D.O.I. displayed strain energy of 11948.16 and 14112.00 J, respectively.

3.3.3 Methods of fixing stud connectors on steel plate (welding and epoxy)

Test results shown in Table 3 indicate in comparison with welding methods, the energy capacity decreases when epoxy glue is used for the same ratio of WPF and same D.O.I. This may be due to a greater strength resistance and capacity of welding, as mentioned before.

3.4. Finite Element Method and simulated models

The model in finite element analysis (FEA) was done by means of ANSYS software. A smeared cracking approach has been used to model the reinforced concrete. The elastic modulus of the material is then assumed to be zero in the direction parallel to the principal tensile stress direction which means that the concrete is not capable of resisting tensile strength exceeding the limit and the modulus of elasticity in tension equals zero. The concrete starts crushing in the elements located directly under the loads when the stresses in compression zone exceed the compressive strength of concrete. In this research, the crushing capability was turned off and cracking of the concrete controlled the failure of the finite element models.

Discrete representation of BRC reinforcements matching the actual reinforcement of concrete slabs was adopted. Three types of elements were selected and adopted to simulate composite slab models. We adopted the following types of elements in present study to simulate the composite slab are: SOLID65 for concrete slab, LINK180 for BRC, SHELL181 for steel plate, and COMBIN7 (Revolute Joint) for stud connector. Each selected element type represents and simulates the actual behavior of each material.

We used the following equation [21]:

$$\left[\frac{f(t)}{k}\right]^{2/3} = V_o.t - \frac{1}{m_s}\int_0^t d\tau \int_0^\tau f(\overline{\tau})d\overline{\tau} - Y(t)_{striker} \quad (2)$$

It can be solved to determine force-time history for impact, by using numerical integration method described by Al-Azawi [22] for slabs. Newton-Raphson equilibrium iteration has been used to solve the nonlinear problem of impact in ANSYS software and displacement convergence criterions have been used in order to monitor the equilibrium.

3.5. Impact analysis results

Analysis results are shown in Fig. 14–17. Because of non-availability of the sophisticated measuring devices of dynamic deflections, maximum transient deflection was used for comparison between theoretical and experimental deflection. Maximum theoretical mid-span deflection of the reference slab is 0.21 mm, while the experimental test gave a maximum mid-span deflection of 0.125 mm. Maximum theoretical mid-span deflection of 0.5 % WPF slab is 0.177 mm, while the experimental test gave a maximum mid-span deflection of 0.105 mm. Maximum theoretical mid-span deflection of 0.75 % WPF slab is 0.127 mm while the experimental test gave a maximum mid-span deflection of 0.09 mm. Finally, maximum theoretical mid-span deflection of 1 % WPF slab is 0.23 mm, while the experimental test gave a maximum mid-span deflection of 0.14 mm. The difference between theoretical and experimental results is related to repetition of strikes in experimental test, which results in accumulated residual deflections. Consequently, the velocity and acceleration of a sinusoidal shape represent a free vibration mode.

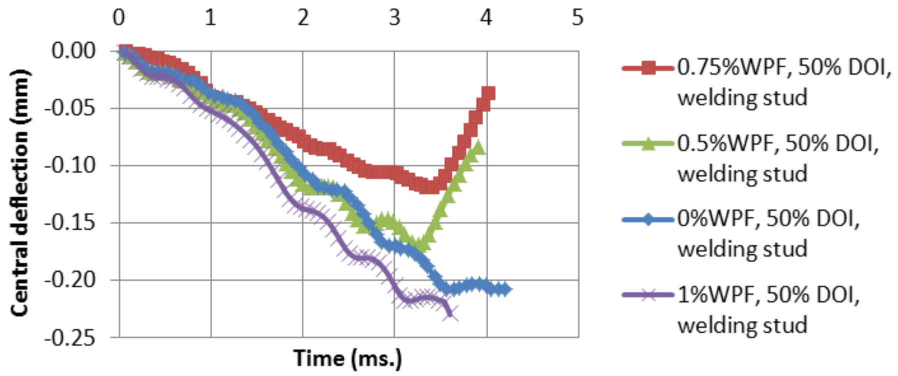

Figure 15. Mid-span deflection vs. time.

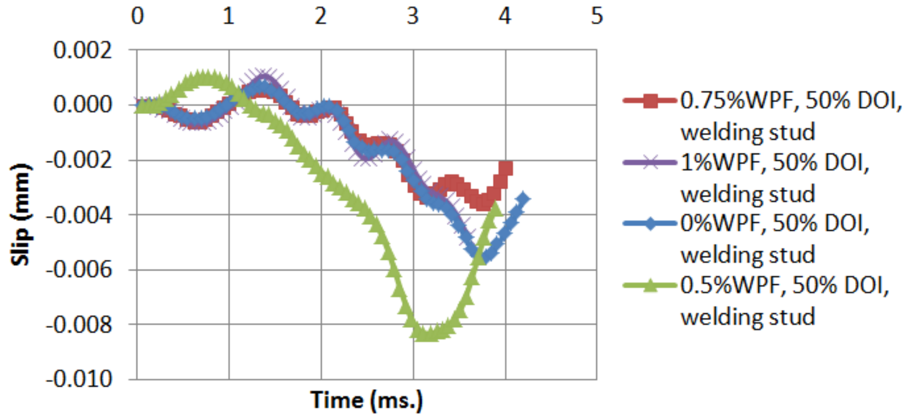

Figure 16. Slip vs. time.

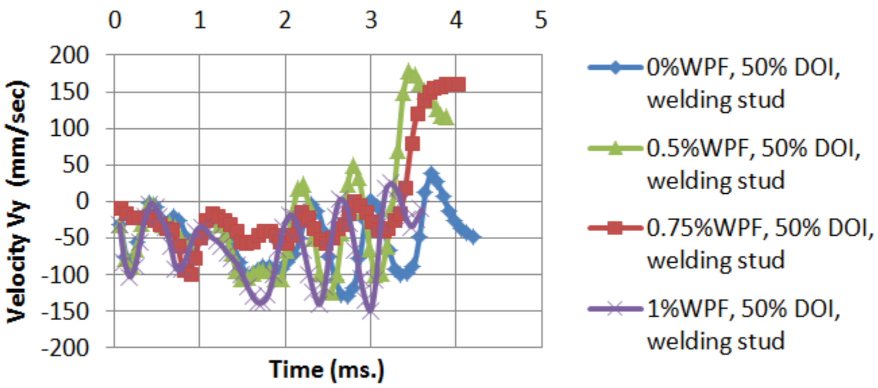

Figure 17. Velocity vs. time.

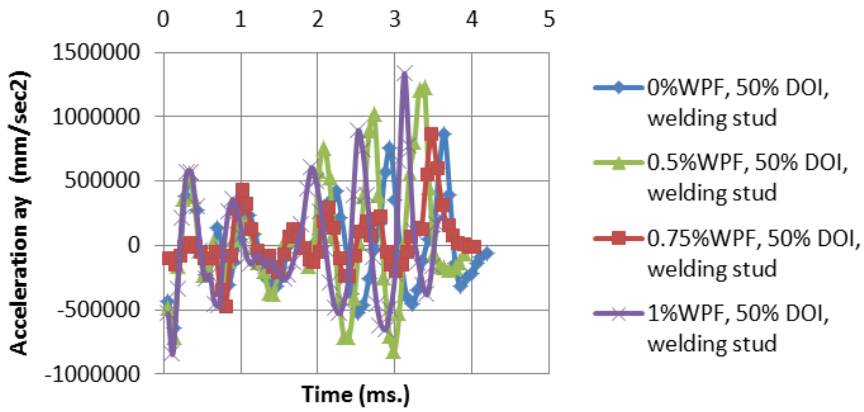

Figure 18. Acceleration vs. time.

4. Conclusions

Based on the results of the simulation and experimental tests, we can summarized the most important points as follows:

Compared with the control specimen, higher contain of WPF (waste plastic fibers) increased the compressive strength of the slabs up to the point of 0.75 % WPF as shown in Fig. 3. There is a drop in values bellow that for the control specimen, when the WPF percentage was equal to 1 %

1. Compared with the control specimen, the compressive strength increased in the slabs containing up to 0.75 % WPF. There is a drop in values bellow that for the control specimen, when the WPF percentage was equal to 1 %. While flexural strength increased when %WPF increased.

2. With WPF percentages growing, the number of blows causing the first crack increases regardless of the degree of interaction between concrete slab and steel plate. However, both the number of blows at failure and maximum deflection at failure experience a drop and a rise respectively for WPF of 0.75 % and higher.

3. The number of blows required to reach first crack and failure is increasing along degree of interaction (for the same WPF percentage) in comparison with 0 % D.O.I.

4. The number of blows at the first crack and at failure stage is less for epoxy glue compared with welding for the same ratio of WPF and identical D.O.I.

5. A low content of plastic fibers up to 0.75 % effectively enhances the capacity of composite slabs and makes the structural response more ductile; volume fraction of plastic fibers equal to 1.0 % slightly improves the number of blows at failure, but remarkably enhances the composite slabs ductility.

6. As WPF percentage increases, the number of blows required to reach the first crack increases regardless of degree of interaction between concrete slab and steel plate, which led to an increase in strain energy capacity of slabs.

7. Energy capacity is increasing along with degree of interaction in comparison with 0 % D.O.I.

8. Energy capacity decreases in case of using epoxy glue in comparison with welding methods for the same ratio of WPF and same D.O.I.

9. A difference between theoretical and experimental results was noticed: the repetition of strikes in the experimental test resulted in accumulated residual deflections.

10. Velocity and acceleration of a sinusoidal shape represent a typical free vibration mode.

References

1. Petkevičius, M., Valivonis, J. Analysis of bending capacity of composite steel-concrete slabs with steel fiber reinforced concrete, in The 10th International Conference “Modern Building Materials, Structures and Techniques”: Selected papers, Vol. 2. Ed. by P. Vainiūnas, E.K. Zavadskas, May 19–21, 2010, Lithuania. Vilnius: Technika, 2010. Pp. 744–751.
2. Roesler, J.R., Altoubat, S.A., Lange, D.A., Rieder, K., Ulreich, G.R. Effect of Synthetic Fibers on Structural Behavior of Concrete Slabs-on-Ground. ACI Materials Journal. 103 (1) 2006. Pp. 3–10.
3. David, F., Rasmus, R., Karin, L. Experiments on Fibre Reinforced Concrete Two-Way Slabs. Fibre Concrete, Prague, Czech Republic. 2013. Pp. 1–10.
4. Hama, S.M. Behavior of concrete incorporating waste plastic as fine aggregate subjected to compression, impact load and bond resistance. Eur J Environ Civ Eng. (2020). https://doi.org/10.1080/19648189.2020.1798287
5. Aziz, K.I., Hama, S.M., Kuhair, H.M.L. Effenciency of Waste Plastic Fiber on Behavior of Composite Steel Plate-Concrete Push Out Test. 2018 11th International Conference on Developments in eSystems Engineering (DeSE), 2018, pp. 335-339, doi: 10.1109/DeSE.2018.00066.
6. Marthong, C., Sarma, D.K. Influence of PET fiber geometry on the mechanical properties of concrete: an experimental investigation. 20(7) 2016. Pp. 771–784. https://doi.org/10.1080/19648189.2015.1072112
7. Hama, S.M. Improving mechanical properties of lightweight Porcelanite aggregate concrete using different waste material" International Journal of Sustainable Built Environment. 6, 2017. Pp. 81–90. http://dx.doi.org/10.1016/j.ijsbe.2017.03.002
8. Zineddina, M., Krauthammerb, T. Dynamic response and behavior of reinforced concrete slabs under impact loading", International Journal of Impact Engineering. 34 (9) 2007. Pp. 1517–1534. https://doi.org/10.1016/j.ijimpeng.2006.10.012
9. Tahmasebinia, F., Remennikov, A. Simulation of the Reinforced Concrete Slabs under Impact Loading. Australasian Structural Engineering Conference (ASEC), 26–27 June 2008. Pp. 088 (1–10).
10. Trevor, D.H., Vecchio, F.J. Behavior of Steel Fiber-Reinforced Concrete Slabs under Impact Load", ACI Structural Journal. 111 (5) 2014. Pp. 1213–1224. DOI: 10.14359/51686923
11. Mahmoud Hama, S. Evalutions of strengths, impact and energy capacity of two-way concrete slabs incorprating waste plastic. J King Saud Univ Eng Sci (2021) 33:337–345. https://doi.org/10.1016/j.jksues.2020.09.007
12. Xiao, Y., Li, B., Fujikake, K. Experimental Study of Reinforced Concrete Slabs under Different Loading Rates. ACI Structural Journal. 113 (1) 2016. Pp. 157–168. http://dx.doi.org/10.14359/51688067

13. Manfred, H., Hermann, P., Alost, S.P. Behavior of Highly Deformable Projectiles in Reinforced Concrete Slabs. Inter-Association Symposium on Concrete Structures under Impact and Impulsive Loading, Berlin, June, 1982. Cited by (Al-Azawi, T.K., “Impact Resistance of Reinforced Concrete Slabs”, Ph. D. Thesis, Sheffield University, Nov. 1984.
14. Al-Hadithi, A.I. Flexural, Impact and Thermal Properties of Polymer Modified Concrete. Ph. D., Thesis, Building and Construction Department, University of Technology. 2005.
15. Iraqi specification No. 5 / 1984. Portland Cement. Central Agency for standardization and Quality Control, Planning Council, Baghdad, Iraq.
16. Iraqi specification No. 45 / 1984. Aggregate from Natural Sources for ncrete. Central Agency for Standardization and Quality Control, Planning Council, Baghdad, Iraq.
17. ASTM C192 / C192M-02, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, ASTM International, West Conshohocken, PA, 2002, www.astm.org. DOI: 10.1520/C0192_C0192M-02
18. ASTM C39/C39M. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. 04.03. 2003.West Conshohocken, PA.
19. ASTM C78. Standard Test Method for Flexural Strength of Concrete Using Simple Beam with Third- Point Loading. Annual Book of ASTM Standard. 2003.
20. ACI 544, Measurement of Properties of Fiber Reinforced Concrete, ACI, West Conshohocken, PA, 1999.
21. Adnan, F.A., Ali, G.A. AL-Khafaji. Nonlinear Finite Element Analysis of Reinforced Concrete Slabs under Impact Loads. Journal of Kerbala University, Vol. 13, No. 1, Scientific. 2015.
22. Al-Azzawi, T.K. “Impact Resistance of Reinforced Concrete Slab”, Ph.D. Thesis, University of Sheffield, England, 1984.

Contacts:

Hashim Suwaid, raedalhiti@gmail.com
Khalil Aziz, k_ibraheem@yahoo.com
Sheelan Hama, drsheelan@uoanbar.edu.iq