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Long–term behavior of composite steel plate-concrete slabs incorporating waste plastic fibers

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Abstract. This research has been conducted to investigate the effect of adding waste plastic fibers (WPF) in concrete on behavior of composites steel plate-concrete slabs. The WPF were produced by cutting plastic bottles used to preserve carbonated beverages. Both mid-span deflection and slip between concrete layer and steel plate are measured using an electronic gauge at 7, 28, 56, 90, 120, 180 and 270 day age. Percentages calculations of plastic fiber by volumetric rates ranging between (0 %) to (1 %) were carried out. Reference concrete slab without plastic fibers was cast for comparison. Short-term test was conducted on the slabs to determine the ultimate load. The tests results showed that 1 % WPF has led to lower value of deflection and highest slip between steel plate and slab concrete. There is a slight difference between the results of 0.75 % and 1 %WPF.

1. *Introduction*

Utilizing waste plastic fiber in concrete not only enhances properties of the concrete but also benefits environment by reducing this type of waste. The main objective of this study is to examine the time-dependent behavior of composite steel-concrete slabs, in which concrete incorporates waste plastic fibers. In addition, we examined other factors such as the degree of interaction and type of connection between stud shear connector and steel plate (weld and epoxy).

Hama investigated the effects of the presence of waste plastic chips on the fresh properties of concrete, as well as strength and impact resistance characteristics of a concrete slab. The tests result indicated a decrease in strength properties and impact, but the compact resistance and energy capacity absorption of concrete improvemed due to the addition of plastic chips as aggregate [1, 2]. In general, adding waste plastic led to reduced workability of concrete [1, 2]. Nibudey et al. studied the performance of concrete in presence of waste plastic fiber (0 to 3 %). Compressive and tensile strength were investigated. Results of tests showed that 1 % waste plastic fiber improved mechanical characteristics of tested specimens compared to reference specimens without fibers [3]. Ganesh et al. investigated the effect of replacing natural fine aggregate with fine waste plastic. Twenty-seven specimens were tested. The sand was replaced by (0.5, 1.0, and 1.5 %) fine waste plastic by volume. Test results showed that 1.0 % fine waste plastic gave the best results in terms of both compressive and tensile strength [4]. Al-Rawi study the flexural behavior of reinforced concrete beams incorporating waste plastic fiber by (0.0, 0.5, 1.0, 1.5, and 2.0 %) as volume fraction. Test results showed a reduction in deflection with an increase in fibers content up to (1%) [5]. Al-Ani studied the possible way to use waste plastic material as fine aggregate in structural elements by evaluating the mechanical properties of concrete. Various ratios of waste plastic were considered (2.5 %, 5.0 %, and 7.5 %) by volume. Test results indicated that the presence of waste plastic reduces concrete workability and decreased the compressive strength and modulus of elasticity compared with control concrete [6]. Faisal et al. studied the influence of ring-shaped waste plastic on flexural toughness of concrete. Results showed an increase in the toughness of about 23 % for (5 mm) plastic width

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and 40 % for 10 mm width [7]. Hama showed that adding plastic fibers to lightweight concrete led to improving its mechanical properties, especially flexural strength [8]. Another study showed that plastic fibers increased the slip between concrete and steel sections in the push-out test [9]. Another study showed that adding plastic aggregate with waste glass powder improved mechanical properties and bond strength compared to specimens with waste plastic without glass powder [10]. Marthong and Sarma [11] investigated the influence of plastic fibers geometry (straight, flattened end deformed, and crimped end fiber). The straight one gave the poorest and weakest bond with concrete matrix among other types while other types clearly improved the anchorage effect. Ollgaard et al. [12] investigated the behavior of shear connectors (stud type) in normal and lightweight concrete. Results showed that the shear strength of the stud shear connector embedded in normal or lightweight concrete was affected by both compressive strength and modulus of elasticity of concrete. The behavior of headed shear connectors on trapezoidal profiled steel sheets push-out tests have been investigated by Lloyd and Wright [13]. Results showed that the shear strength of connectors was affected by the stiffness of transverse reinforcement. Shim et al. [14] studied stress-slip relation of large diameter stud connector using a static push-out test.

There is no existing research about the effect of plastic fibers on the long-term behavior of steel-concrete slabs under sustained load. Therefore, this research provides useful data in this field.

2. Methods

2.1. Material

Ordinary Portland cement (OPC – Type I) was used to cast all specimens. Test results indicate that the adopted cement conforms to the Iraqi specifications (I.Q.S.) No.5/ 1984 [15] as shown in Tables 1 and 2, respectively.

Table 1. Physical properties of cement.

Physical properties	Test result	Limits of I.Q.S No.5/1984
Specific surface area (Blaine Method) (m^2/kg).	300	> 230
Setting time :		
-Initial setting (min.)	90 min.	≥ 45 minute
-Final setting (min.)	225	≤ 600 minute
Compressive strength of mortar (MPa):		
3-days	21	≥ 15
7-days	27	≥ 23
Soundness % (Autoclave)	0.2	≤ 0.8

Table 2. Chemical properties of cement.

Oxide composition	by weight%	Limits of I.Q.S No.5/1984
CaO	61	–
SiO_2	19.84	–
Al_2O_3	5.28	–
Fe_2O_3	4.2	–
SO_3	2.49	≤ 5 %
MgO	2.48	≤ 2.8 %
Loss on Ignition (L.O.I.)	3.8	≤ 4 %
Lime saturation Factor (L.S.F.)	0.92	0.66-1.02
Insoluble residue (I.R.)	1.13	≤ 1.5 %

Natural fine aggregate from the local Al-Akhadir area was used. Table 3 presents the sieve analysis. Table 4 shows physical properties of the used sand.

Table 3. Sieve analysis of fine aggregate.

Sieve size(mm)	% passing	Limits of I.Q.S No. 45/1984 % passing Zone (2) [16]
10	100	100
4.75	91	90–100
2.36	79	75–100
1.18	67	55–90
0.6	48	35–59
0.3	15	8–30
0.15	2	0–10

Table 4. Physical and chemical properties of the used fine aggregate.

Physical properties	Test result	Iraqi Specification [16]
Specific gravity	2.60	
Sulfate content (SO_3%)	0.42%	0.5 % (max)
Absorption%	0.75%	–
Fineness modulus	2.97	–

Crushed gravel from the AL-Nibaey area with a maximum size of 10 mm was used as coarse aggregate. Tables 5 and 6 present sieve analysis of the coarse aggregate and the physical and chemical properties of coarse aggregate respectively with the limit specified by Iraqi Specification No.45/1984.

Table 5. Sieve analysis of coarse aggregate.

Sieve Size (mm)	% Passing	Iraqi specifications No. 45/1984
12.5	100	100
9.5	86	85–100
4.75	5.5	0–25
2.36	1	0–5

Table 6. Physical and chemical properties of coarse aggregate.

Properties	Test results	Iraqi specifications No.45/1984
Specific gravity	2.65	–
Sulfate content	0.09	≤ 0.1
Absorption %	0.52 %	–

The geometrical characteristics of plastic fibers throughout the experimental work are illustrated in Table 7. A shredder machine was used to cut plastic, see Fig. 1. Fibers were added to the mixes with these ratios by volume of mixture: 0.00, 0.50, 0.75, and 1.00 respectively. Two types of epoxy were used for connection between stud and steel plate, and between steel plate and concrete slabs. Each type consists of two parts (A and B) which were mixed with specific percentages to get the final resin.

Table 7. Characteristics of plastic fibers.

Properties	Length(mm)	Width(mm)	Thickness(mm)	Specific gravity (gm/cm^3)
Plastic fibers	35	4	0.30	1.1

Headed shear stud connector is commonly used in composite structures, and therefore was selected for the RC composite slabs. The diameter of the stud is (6 mm) with height of (35 mm), and the head diameter is (10 mm). The mechanical properties comply with ASTM A615-14 [17], see Table 8.

Table 8. Tensile properties of the used stud shear connectors and steel plate.

Details of steel	Yield Tensile Strength (MPa)	Average of Ultimate Tensile Strength (MPa)	Modulus of Elasticity (MPa)	% Elongation at Ultimate Stress
Steel plate (Actual thickness 3 mm) 93 mm	320	420	203000	18
Stud (Actual dia. 6 mm)	610	760	201000	20

Figure 1. Preparation of plastic fibers: shredding machine(left), and plastic fibers(right).

Steel plate with dimensions (1000*1000) mm, properties listed in Table 8, was used in the present study. According to ASTM A36/A [18], the yield and tensile strength were evaluated. The steel plate and the welded stud shear connectors before casting concrete are shown in Fig. 2.

Figure 2. Steel plate with welded stud shear connectors.

WWF (Welded Wire – Fabric) is the type of reinforcement that was used to reinforce the RC composite slabs. The mechanical properties and geometry are listed in Table 9. The WWF was placed (20 mm) from the top. According to ASTM A185-07, the yield and tensile strength were evaluated.

Table 9. WWF geometry and mechanical properties.

Square opening (mm)	Yield Tensile Strength (MPa)	Ultimate Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Elongation at Ultimate Stress (%)
90*90	520	630	210000	11

2.2. Mixing Proportion And Specimens Tests

The mix proportions were listed in Table 10. Waste plastic fibers were added to the chosen mix as a percentage of the volume of concrete (0, 0.5, 0.75, and 1 %). Compressive strength and flexural strength were measured according to ASTM C39-03 [19] and ASTM C78-03 [20] respectively. An average of three specimens was considered for each test.

Table 10. Mix proportions.

Symbol	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	% (w/c)	Plastic fiber (%)	Compressive strength (MPa)	Flexural strength (Mpa)
1	420	720	950	0.5	0.00	26.91	2.8
2	420	720	950	0.5	0.50	26.99	3.5
3	420	720	950	0.5	0.75	29.49	4.34
4	420	720	950	0.5	1.00	24.78	4.9

2.3. Composite Slab Details, Casting, Compaction, and Curing

Wood frames were fixed on the steel plate, and the BRC was fixed about 20mm from the top of the frame for concrete casting to form a composite slab. Compactions were made by using a mechanical vibrator to get more uniform mixing and prevent any voids inside concrete. Steel trowel was used to level the top surface of slabs and smooth it; Fig. 3 shows the slabs after casting. The composite slab details are clarified in Fig. 4. Before the tests, all specimens were cured in a fresh water tank to ensure the required time for the concrete to complete the hydration processes. The composite slab was warped in a nylon sheet to prevent evaporation during the hydration processes as well.

Figure 3. Slabs after casting.

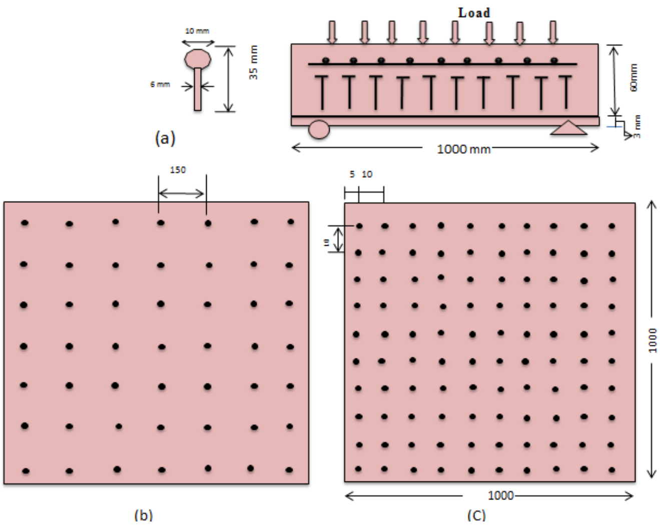

Figure 4. Details of the composite slab (all dimensions in mm)
a – Front view of the composite slab; b – Top view of partial composite slab (50 % D.O.I); c – Top view of the full composite slab (100 % D.O.I)

2.4. Composite Slabs Tests

2.4.1. Short-term test

The reinforced concrete composite slabs were tested under static short-term loading. A slab was resting at the testing machine with supports around the perimeter of the slab (simply-supported). A 5 mm thick steel plate was put on top of the slab with reinforcing steel bars were distributed at the top face of the steel plate in one layer. We added up to five steel plates one after another separated by steel bars (see Fig. 5). The load was applied at the center (top) of the R.C. slab utilizing a thick steel plate to distribute the loading. Initially, the load applied was up to (5 kN); then it was reset to zero to make the slab rest, and there was no effect of the friction that developed in supports. The load was applied gradually (load control) and the deflections and slip were recorded at each load step until the failure of the slab.

2.4.2. Long-term test

The long-term loading was tested by applying uniform service loading (around 40 % of ultimate load) at the top of the composite slab utilizing an equivalent weight of sand. The deflections and slips were measured at various times in a span of nine months using two fixed dial gauges: one at the end of the slab to measure the cumulative slips, and the second at the center bottom face of composite slabs to measure the deflections.

Deflection and slip were measured at mid-span and interface between the concrete slab and steel plate, respectively, by using a dial gauge, which has an accuracy of (0.001 mm) as shown in Fig. 6.

Figure 5. Short-term test

Figure 6. Dial gauge.

2.4.3. Parametric Study

Ten slabs were tested: one under static load to fix the ultimate load, and nine under sustained load (40 % from ultimate load). The slabs were marked as shown in Table 11. Three parametric studies were taken in this work:

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

Table 11. Specimen's details.

Mark	% WPF	% Degree of interaction	Type of connection
H1	0.75	50	Welding
H2*	0	100	Welding
H3	0.75	100	Welding
H4	0.75	No Stud	Glued plate by epoxy without stud
H5	0.75	0	N/A Concrete slab cast directly on the plate without a connection
H6	0.5	50	Welding
H7	1	50	Welding
H8	0.75	50	Glued stud by epoxy
H9	0	50	Welding
H10	0	0	Reference without plate with 74 mm RC slab only

All specimens were tested under sustained load but H2* was tested under short-term load.

3. Results and Discussion

3.1. Short Term Tests

A short-term test was done for composite slab (H2) with (100 % D.O.I) and (0 % WPF) to determine the ultimate load. The max deflection was 0.402 mm at 12.5 KN/m^2 maximum load. Load–deflection is shown in Fig. 7, and load–slip curve of composite slab behavior is shown in Fig. 8.

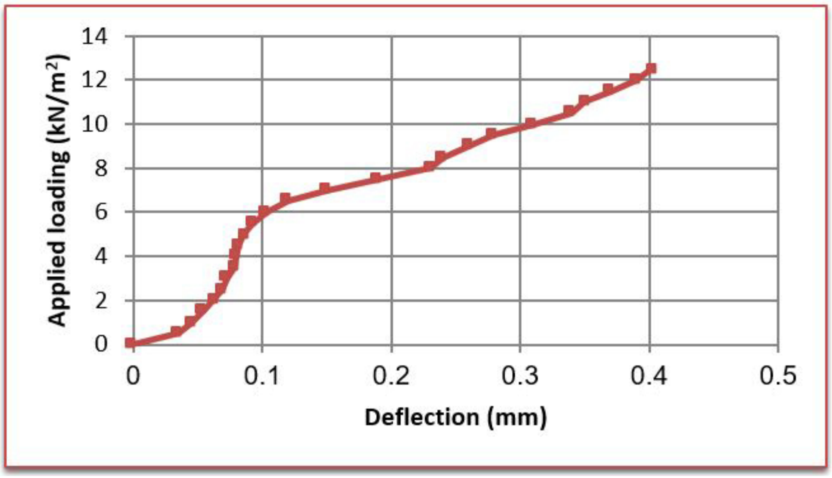

Figure 7. Load–deflection of the short-term test.

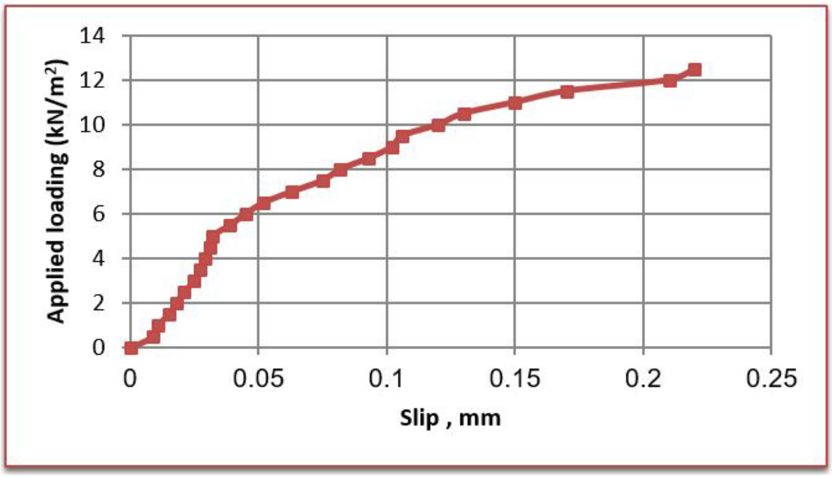

Figure 8. Load–slip curve of the composite slab (Short term tests).

3.2. Time – Depended Test

A total of nine specimens were tested under service loading of (40 %) from the ultimate loading which is equal to (5 KN/m^2). In experimental tests, dial gauges are fixed at the interface between reinforced concrete slab and steel plate to measure the relative horizontal displacement (slip). Another one was also fixed at the bottom of the specimen at the mid-span to measure the central deflection. The dead load was applied uniformly by brushing the sand over the slab. The tests yielded the following results according to considered parametric study.

3.2.1. Effects of Waste Plastic Fiber Percentages (WPF)

Fig. 9 shows deflection–time relationships for different (% WPF). The percentage of added fiber related decrease in deflection compared to reference slab (H9 without WPF) was 10.11 %, 37.19 %, and 40.14 % for 0.5 %,0.75 %, and 1 % WPF, respectively, at the age of (270 days). From the results, one can see that (1 % WPFC) gave the lowest deflection. The mechanical properties test showed that adding (1 % WPF) produced the best flexural tensile strength, which may be the reason why adding (1 % WPF) resulted in a deflection decrease.

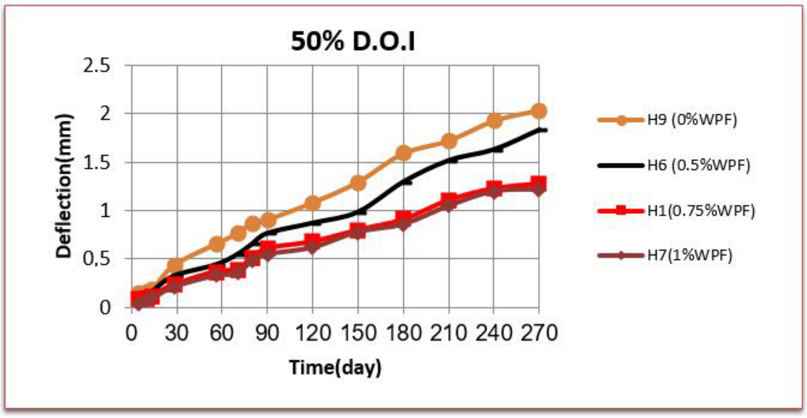

Figure 9. Effects of waste plastic fiber on deflection with time.

The slip values for various percentages of WPF are drawn in Fig. 10. The maximum slip values for H7 (1 % WPF) are more than other percentages and increase with time. It seems that plastic fiber distribution affected the adhesion between the concrete slab and steel plate and this reflects in slip values [9]. In comparison with reference concrete H9, the slip values are higher for the same age (270 days) with 8.3 % and 18 % for H6 (0.5 %) and H1 (0.75%) WPF respectively, but H7 (1 % WPF) has slip higher than the reference concrete by 23 %.

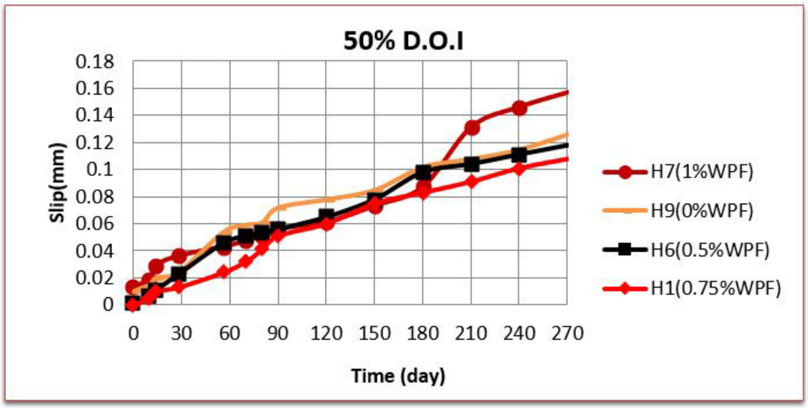

Figure 10. Effects of waste plastic fiber on the slip with time.

3.2.2. Type of Connection between Stud Shear Connector and Steel Plate (Welding and Epoxy)

Two methods were used to fix stud shear connectors to the steel plate: welding, and epoxy adhesive. Fig. 11 and Fig. 12 show that deflection and slip increased in the case of fixing the stud shear connectors with epoxy at the top of steel plate (H8) compared with welding studs shear connectors (H1), since epoxy is more flexible than welding. The deflections of H8 were higher than H1 by 2.3 % for the same age (270 days). The use of welding to fix the stud connectors increases the stuffiness of the composite slab which led to a decrease in deflection and the slip between concrete and steel plate. These results can also be explained according to the results of the push-out test carried by Azizi et al. [9], who found that the strength of the stud connector is higher in the case of welding connection with steel plate.

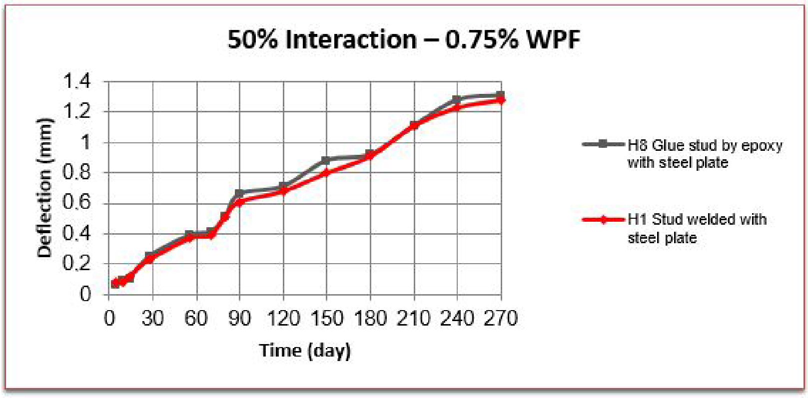

Figure 11. Effects of type of connections between shear stud and a steel plate on deflection with time.

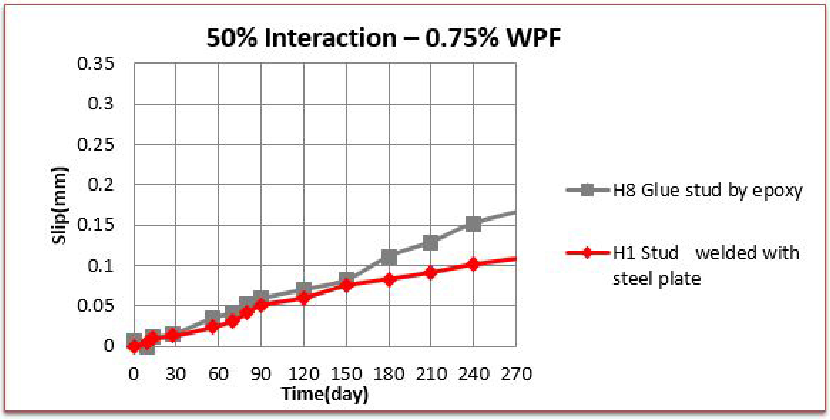

Figure 12. Effects of type of connections between shear stud and a steel plate on the slip with time.

3.2.3. Degree of Interaction (D.O.I)

Fig. 13 illustrates the relationship between deflection and time for (100 % D.O.I) H3, (50 % D.O.I) H1. H1 and H3 were compared with H5 (0 % D.O.I concrete that was cast directly over the plate without any shear connectors). Compared with H5 (using as control slab), at the age of 270 days, H3 has deflection lower by 57.5 %, while H1 has deflection lower by 42.1 %. Higher D.O.I gave lower deflection, H1 has higher deflection than H3 by 36.2 % at the age of (270 days) as show in the full interaction which gives the lower value of deflections because of full integrity between concrete slab and steel plate, so that the rigidity and stiffness become more rather than the 50 % and zero interaction. We compared two slabs with 0 % (D.O.I): H4 had concrete glued to the plate directly using epoxy, while H5 was cast directly above plate without any type of epoxy (0 % D.O.I), i.e. there was no interaction between concrete and steel plate. H5 has higher deflection than H4 by 36.4 % at the age of (270 days), because each material works separately, causing deflection to increase (see Fig. 14). Fig. 15 shows that the slip increases and becomes higher when the reinforced concrete slab was cast directly above the steel plate without any connections (0 % D.O.I), so that there are no connection nodes, no volume contact, and the two materials work separately. The specimens H3 and H1 (100 % and 50 % D.O.I) have slips less than specimen H5 by about 83 % and 76 % respectively at the same age (270 days), and H3 has slip higher than H1 by 31 %. When the interaction is full, the composite action works, so the stiffness and rigidity increase because of increasing in a moment of inertia and equivalent modulus of elasticity for a composite slab with full interaction and partial interaction compared to a composite slab without shear connection. Fig.16 shows the variations of slip in two types of interactions. First goes H5, the concrete slab cast above the steel plate without interactions, second is H4 specimen, and then the connections by epoxy without stud shear connectors. H4 has lesser slip than H5 by 28 %. This is due to the shear force that developed by the vertical force transfer from glue to the steel plate: the shear force distributes and is equal in opposite directions between the concrete slab and steel plate, therefore the slip was reduced and became lower than H5 specimen.

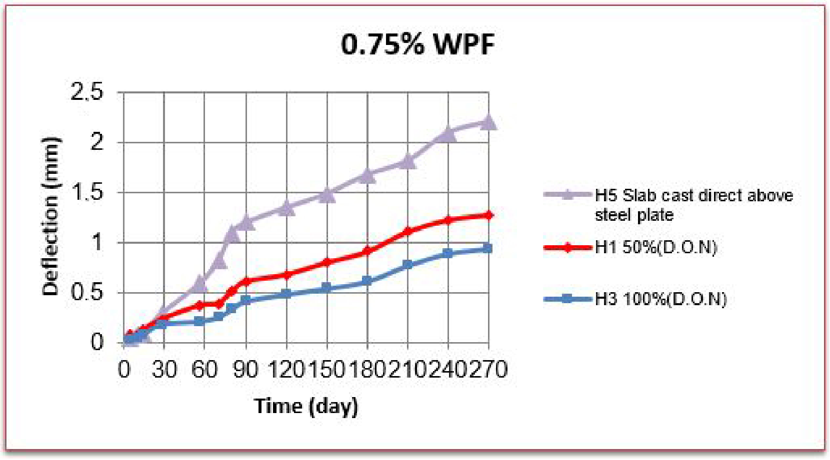

Figure 13. Effects of degree of connections on a deflection with time.

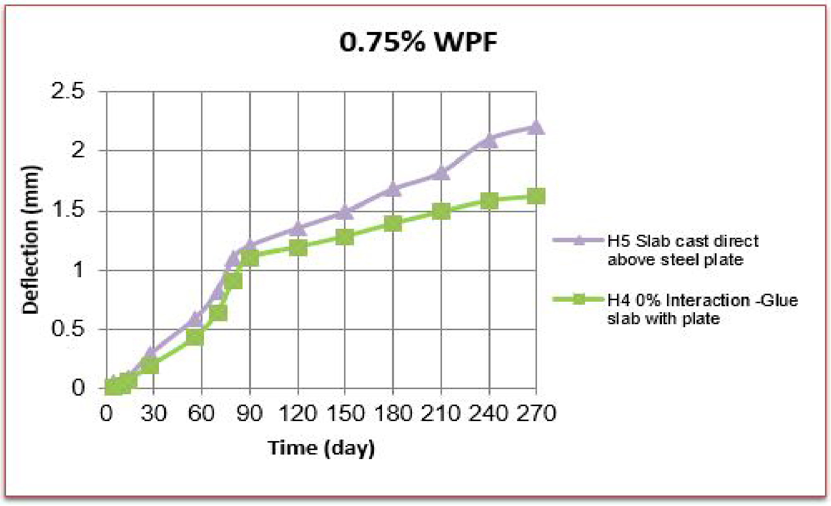

Figure 14. Comparison between deflection of slabs H5 and H4.

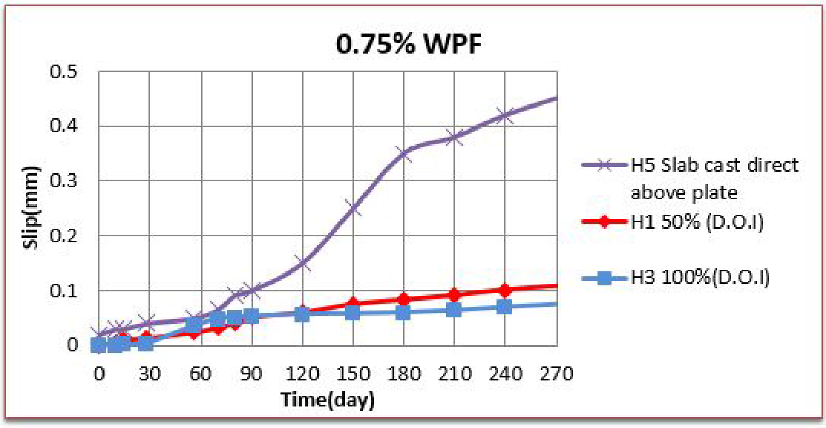

Figure 15. Comparison between the slip of slabs H1, H3, and H5.

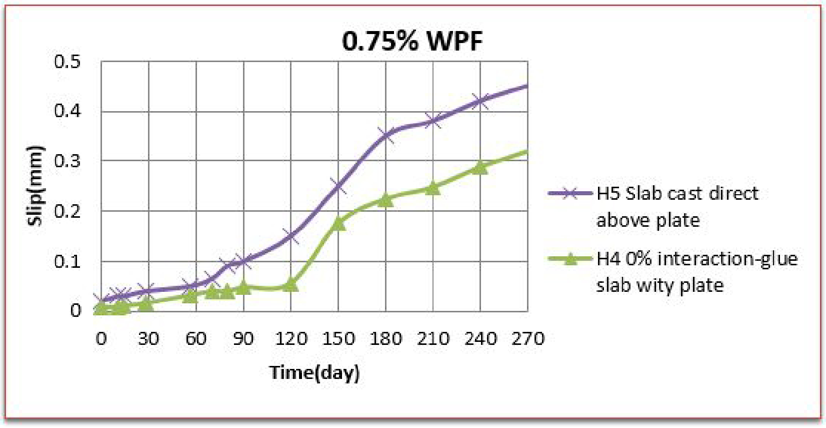

Figure 16. Comparison between the slip of slabs H4 and H5.

4. Conclusions

This experimental investigation shows that PET bottles can become a low-cost material, which can help to resolve solid waste problems and prevent environmental pollution, while at the same time enhancing the properties of concrete as concluded in this study. The results are as follows:

1. Decreased deflection due to adding the fiber in comparison with control slab (without WPF) by 4.3 %,7.2 %, and 11.6 % for 0.5 %, 0.75 %, and 1 % WPF, respectively at 270-days ages.
2. The deflection decreased when the degree of interaction increased, the percentages of decreasing were 57 and 42.1 % for the degree of interactions 100 and 50 %, respectively, compared with the reinforced concrete slab cast directly above steel plate without any connection types for the same age (270 days).

3. The deflection increases in the case of the non-composite slab as compared with the composite slab of 50 % D.O.I. at the same age (270 days) by 41 %.
4. The deflection increases in the case of gluing the stud connectors to steel plate by epoxy compared with welding stud connectors by (2.3 %) at the same age (270 days).
5. The slip increases as the percentage of WPF increases and the maximum value of slip at (1 % of WPF) equals 23 % compared with the control specimen at the same age (270 days).
6. The slip decreases as the degree of interaction goes higher. The percentages of the slip decrease were 83 % and 76 % for 100 % and 50 % D.O.I., respectively, as compared with no interaction case at the same age.
7. In the case of welded stud connectors, the slip is lower than in other types of connections compared with the control specimen at the same age.

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