The Influence of Steel Fibers on the mechanical properties and thickness of precast concrete panels

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Abstract. Concrete is well-known with its brittleness, low tensile strength and tensile strain capacities. This performance considered as one of the most crucial constraints that facing precast concrete industry. However, it could be improved by the addition of steel fibers which have been used widely in the last few decades. Hence, higher ductility and better arresting ability to crack propagation could be achieved. In Iraq, the precast concrete panels (flags) are commonly used for roofing and usually produced from plain concrete. This study aimed to add small volume fraction of steel fiber to the precast concrete panels to improve the handling and transportation process and assess their breaking load in accordance to the requirements of the Iraqi standard specification No.1107-87. Concrete panels with (400×400mm) and different thicknesses (30 and 50mm) were produced. Different steel fiber volume fractions (0%, 0.25%, 0.5%, and 1%) were incorporated. The mechanical properties (compressive strength, splitting tensile strength, and flexural strength) for the concrete mixes were investigated. The test results of this study encourage the incorporation of small volume fraction of steel fiber in production of precast concrete panels to reduce the spoilage upon handling and transportation of precast concrete panels. The breaking load of steel fiber concrete panels has been improved by 142% relative to reference concrete panels. It was also revealed that the concrete panel thickness could be reduced when the steel fiber content increased, which could be of great interest with regards to the economic side. This is because of reducing the amount of raw materials used in production of concrete panels and thereby reducing the impact on the environment.

The statistical analysis was accomplished by using the SPSS program.

Keywords: concrete panels, concrete flags, precast concrete, steel fibers, steel fibers concrete.

1. Introduction

The precast concrete industry had been considered as a major industry worldwide in the last decades, and it had gained a great foothold over the cast in situ construction due to the important advantages of the precast concrete. However, the prefabricated concrete industry had its own constraints and disadvantages. One of the main obstacles that facing the precast concrete industry is the damage in the concrete units occur during handling and transportation process, which is related to the brittle behavior of the concrete [1].

In Iraq, the precast concrete panels are considered as one of the most popular flooring tiles, especially for outdoor applications. It has a high durability with regards to weather condition such as raining, sunlight and high temperature fluctuations [2]. However, this industry suffers from several problems such as damages during transportation and handling [3]. Recently several native research works were made to improve the behavior and aesthetical appearance of the precast concrete panels [2, 3, 4, 5, 6]. Salih et al. [2] suggested in their work using of steel wire mesh (commercially known as chicken wire) to improve the flexural strength of the concrete panels. They had indicated that this mesh improved the ultimate load at rupture for the concrete panels up to 21% relative to plain concrete panels. Also, they indicated that the
good concrete mix designing was essential to provide adequate concrete panels with regards to requirements of Iraqi slandered specification No.1107-87[7].

Bazgir [8] indicated that steel fiber had contributed to significant advantages in precast concrete industry such as floor slabs and parking garage and it could be possible to reduce the concrete unit’s thickness, which resulted in reducing the required quantities of raw materials and reflected positively on the economic side.

Most of the local work had focused on using plastic fiber or mesh to reinforce the precast concrete panels while rare investigations were found on using steel fiber to improve the production of precast concrete panels. Fadhil and Yaseen [3] suggested that precast concrete panels could be economically improved by adding waste plastic fibers. They were used 0.5%, 1%, and 1.5% of waste plastic fiber as volume fraction. The results showed that the optimum fiber content was 1%, where the flexural strength and impact resistance improved by 69% and 228.6% respectively. They had also indicated that using of waste plastic fiber compensating the reduction in panel thickness (by 25%) while maintaining the flexural strength and impact resistance as in the plain concrete panels with higher thickness, which provide an economic benefit. Mahmmod et.al [5] had used 1.5% and 3% of polyethylene terephthalate fibers to reinforce precast concrete panels. They had indicated that using of 1.5% polyethylene terephthalate fibers as volume fraction with 30 mm length improved the breaking load by 46% relative to plain precast concrete panels.

Abdul Rasool et.al. [6] were used plastic and metal wire mesh to reinforce the precast concrete panels. They had found that the plastic had improved breaking load by 25%, while the metal mesh had breaking load by 35% relative to plain concrete panels.

Nehme et al. [9] had investigated the mechanical properties of concrete panels that contains both steel fiber and steel reinforcing mesh, they had concluded that the steel fiber had improve the load-deflection behavior and load capacity of the concrete panels. Although a significant reduction workability of the concrete was noted, especially when 90 kg/m3 of steel fiber was used.

On the other hand, Jongvivatsakul et al. [10] had use the steel fiber precast concrete panels in strengthening of reinforced concrete beams in shear. They had used different steel fiber volume fraction up to 1.5%. The result indicated a positive proportion between crack arresting ability and steel fiber content for the precast concrete panels.

An improvement in impact resistance was indicated for steel fiber concrete panels was recorded by Jamnam et al. [11] the investigation included production of concrete panels with different thickness between 10-100 mm and steel fiber content between 1% and 3%. The result showed that as the steel fiber content and panels' thickness increased, the impact resistance improved and less damage was showed on the back surface of the concrete panels.

Meng with his collogues [12] had studied the effect of fiber reinforced polymer fabric (FRP) on the flexural performance of ultra-high strength concrete panels. They used glass and carbon fiber reinforced fabric with two types of ultra-high strength concrete mixtures with and without steel fiber 2%. The concrete panels are reinforced with different number of fabric layers. They concluded that the mixture without steel fiber and reinforced with (FRP) are brittle in flexural and did not increase the load carrying capacity of panels. On the other hand, the mixture with 2% steel fiber and reinforced with (FRP) fabric are ductile in flexural and demonstrated 14% higher load than mixture without steel fiber. Also, the use of dual layer of glass fabric with steel fiber mixture can increased the strength by 49% while the use of single layer of carbon fiber led to 54% increase in the strength of the concrete panel.

2. Aim and scope
The main aim of this study is to assess the improvement in ultimate load at rupture of concrete panels by adding small volume fractions of steel fiber (0.25, 0.5, and 1%) relative to plain concrete panels. It is also aimed to investigate the possibility of reducing the concrete panel thickness without affecting the required load capacity at rupture (as indicated by the Iraqi slandered specification No.1107-87) by increasing the
steel fiber content. Four concrete mixes with (0%, 0.25%, 0.5%, and 1%) steel fiber content were produced. Concrete panels with (400×400mm) and different thicknesses (30 and 50mm) were cast. The ultimate load at rupture for the concrete panels were examined at age of 28 days and compared with the requirements of Iraqi slandered specification No.1107-87. Compressive, splitting and flexural strength were also evaluated for all concrete mixes at age of 28 days.

3. Experimental program

3.1 Materials

3.1.1 Cement: ordinary Portland cement type I was used, the chemical and physical properties of cement were in complies with ASTM C150 [13].

3.1.2 Fine aggregate: well graded natural sand with a maximum size of 4.75mm was used. The specific gravity, water absorption, and sulfate content for the sand were 2.64, 1%, and 0.23% respectively. The properties of the sand were conforming to ASTM C33 [14].

3.1.3 Coarse aggregate: Crushed gravel with a maximum size of 14mm was used. The specific gravity, water absorption, and sulfate content for the sand were 2.68, 0.5%, and 0.08% respectively. The grading and physical properties of the coarse aggregate conformed to the ASTM C33 [14].

3.1.4 Steel Fiber: hooked end steel fiber with 35mm length and 0.6mm diameter (aspect ratio 58) was used as shown in Figure 1. The tensile strength and density of steel fiber were 1060 N/mm² and 7800 kg/m³ respectively. Steel fiber properties were in conformance with ASTM A820 [15].

3.1.5 Chemical admixture: high range water reducing admixture (HRWRA) commercially known as Hyperplast PC200 was used, this admixture was in complies with ASTM C494 type A & G [16].

3.1.6 Water: Tap water was used for mixing and curing of specimens up to 28 days.

Figure 1. Steel fiber used in the study

3.2 Concrete mix design and mixes proportions
Based on the British mix design method, the concrete mix proportions were selected as presented in Table 1. The selected $f_{c'}$ was 35 N/mm².
Table 1. Concrete mixes proportions

| Mix designation | Cement kg/m³ | Fine aggregate kg/m³ | Coarse aggregate kg/m³ | HRWRA l/100 kg cement | w/c | Steel fiber kg/m³ |
|-----------------|--------------|----------------------|------------------------|------------------------|-----|-------------------|
| R               | 420          | 780                  | 1065                   | 0.25                   | 0.32| 0                 |
| F0.25%          | 420          | 780                  | 1065                   | 0.25                   | 0.32| 19.5              |
| F0.5%           | 420          | 780                  | 1065                   | 0.35                   | 0.32| 39                |
| F1%             | 420          | 780                  | 1065                   | 0.5                    | 0.32| 78                |

3.3 Mixing, casting and curing
Mixing procedure was applied in compliance with ASTM C192 [17]. The dry constituents were added first to the mixer and mixed for 2 minutes, 2/3 the mixing water was added to the dry constituents and mixed for 3 minutes followed by 3 minutes rest. The chemical admixtures were dissolved in the rest amount of water and feed to the mixer and mixed for 2 minutes. Finally, steel fiber was added to the mixer and mixed for 2 minutes.

The concrete panels were cast in plywood forms with (400×400mm), concrete panels with different thicknesses (30 and 50mm) were produced from each mixture. To assess the compressive strength, 100 mm cube specimens were used, while (100×200mm) cylinder specimens were cast to evaluate the splitting strength, and (100×100×400mm) prism specimens were cast to investigate the flexural strength for each mix. All specimens were covered with nylon sheet for 24 hours, then after de-molding all specimens were cured in tap water up to 28 days.

4. Results and discussion

4.1. Compressive, splitting, and flexural strength
The compressive strength test was performed on 100mm cube specimens in accordance with B.S 1881: part 116 [18]. The splitting tensile strength was carried out on (100×200mm) cylinder specimens according to ASTM C496 [19]. The flexural strength test was measured on (100×100×400mm) prism specimens. Simply supported beam with two-third point loading in compliance with B.S 1881: part 118 [20]. The three tests were carried out at age of 28 days, and their results are presented in Table 2 and Figure 2. The results indicated that adding steel fiber had slightly improved the compressive strength, the percentage of increase in compressive strength for specimens F0.25%, F0.5% and F1% relative to specimens of mix R were 6.8%, 9.8%, and 12.8% respectively. Lee and his colleagues agree with these results [21], they indicated that the use of a steel fiber up to 2% volume fraction could slightly improve the compressive strength and this effect is varied depending on fiber and mixture characteristics. On the other hand, the results show better performance for steel fiber concrete with regards to splitting and flexural strength relative to the reference mix. The percentage of increase in splitting tensile strength for specimens of mixes F0.25%, F0.5% and F1% relative to specimens of mix R were 37.5%, 70.8%, and 116.7% respectively, while The percentage of increase in flexural strength for specimens of mixes F0.25%, F0.5% and F1% relative to specimens of mix
R were 39.5%, 76.3%, and 123.7% respectively. These improvements are related to the ductility improvement and better crack arresting ability achieved by adding steel fiber. The same finding was indicated by Jongvivatsakul et al.

Table 2. Test results for compressive, splitting, and flexural strength of the concrete mixes at age of 28 days.

| Designation | Compressive strength N/mm$^2$ | Splitting tensile strength N/mm$^2$ | Flexural strength N/mm$^2$ |
|-------------|--------------------------------|------------------------------------|----------------------------|
| R           | 40.0                           | 2.4                                | 3.8                        |
| F0.25%      | 42.7                           | 3.3                                | 5.3                        |
| F0.5%       | 43.9                           | 4.1                                | 6.7                        |
| F1%         | 45.1                           | 5.2                                | 8.5                        |

Figure 2. Test results for compressive, splitting, and flexural strength for concrete at 28 days.

4.2. Ultimate load at rupture for concrete panels
This test was carried out in accordance with Iraqi stranded specification No 1107-87. Concrete panels with (400×400mm) (as length × width) and 30 or 50mm (as thickness) were cast from each concrete mix. All panels were cured in a tap water up to 28 days. One-point loading test was carried out by means of hydraulic compression machine with capacity of 2000 kN with a stress rate of about 1.0 kN/10 sec, as shown in Figure 3. The test results are presented in Table 3 and Figure 4. The results showed that increasing the steel fiber content will improve the breaking load for the concrete panels. The percentage of increase in the ultimate load recorded for panels with 50mm thickness made from mixes F0.25%, F0.5%, and F1% relative to concrete Panels made from mix R were 10.7, 74.5, and 141.8% respectively. This enhancement is due to the better ductility and cracks arresting achieved with steel fiber. It is also clear that all concrete panels had an acceptable breaking load with regards to the requirements of the Iraqi standard specification No 1107-87 which has specified 8.9 kN as an acceptable ultimate breaking load for panels with (400×400×50mm).
On the other hand, it could be seen that reducing the thickness of the concrete panels from 50 mm to 30 mm led to reducing the ultimate breaking load. But at the same time, all concrete panels contained steel fiber showed an acceptable breaking load with regards to the requirements of the Iraqi standard specification and provided breaking load higher than 8.9 kN. However, the concrete panel made of mix R and 30 mm thickness considered unacceptable according to specifications. This finding could reflect on economic benefits due to reducing the demand for raw materials incorporated in producing these concrete units. It will also reduce the weight of these concrete units up to 40% and thereby reduce its impact on roofing. Same finding was indicated by Fadhil and Yaseen [3].

![Figure 3. Test for concrete panels](image)

**Table 3. Test results for the ultimate load capacity for concrete panels with different thicknesses and different steel fiber contents at 28 days.**

| Designation | Breaking load for precast concrete panels kN | Requirements of Slandered specifications Breaking load for concrete panels (400×400×50) mm (kN) | Percentage of reduction in breaking load between 30 mm and 50 mm panel thicknesses % |
|-------------|---------------------------------------------|-------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Panel thickness 30 mm | Panel thickness 50 mm |                                                                                                  |                                                                                 |
| R           | 5.57                                       | 9.43                                              | 8.9                                                             | -40.9                                                              |
| F0.25%      | 8.99                                       | 10.44                                             | 8.9                                                             | -13.9                                                             |
| F0.5%       | 13.59                                      | 16.46                                             | 8.9                                                             | -17.4                                                             |
| F1%         | 17.3                                       | 22.8                                              | 8.9                                                             | -24.1                                                             |
5. Statistical analysis

By using the data resulted of this study, a statistical analysis was made to figure out the relation between the ultimate load of the concrete panels and the panel thickness and steel fiber content. The Statistical Package for Social Sciences version 26 (IBM-SPSS-26) was used for this purpose. The correlation between the variables was assessed by a bivariate method, and the results are given in Table 4. The Pearson correlation indicated that both panel thickness and steel fiber content are positively affecting the ultimate load of the concrete panels. Although, it could be noted that the steel fiber content is more influential than panel thickness on the ultimate breaking load of the concrete panels.

Linear regression model was used to estimate the ultimate breaking load of the concrete panels based on the concrete panel thickness and steel fiber content. Table 5 showed that the adjusted R square for the predicted model is 0.943, which indicated a high accuracy for the suggested formula. The statistical significance of this model is approved by ANOVA test as given in Table 6, where the statistical significance was less than 0.05. The regression coefficients of the suggested model are listed in Table 7 and the regression formula is given by equation 1:
Where:
\[ UL = 1.749 + 0.171TH + 11.76F \]  
(1)

**Table 4:** Pearson correlation between the ultimate load capacity of the concrete panel, panel thickness and steel fiber content.

|                  | Ultimate load | Panel thickness | Fiber content% |
|------------------|---------------|----------------|----------------|
| **Correlation**  |               |                |                |
|                  | Pearson Correlation | .328 | .923* |
| Ultimate load    | Sig. (2-tailed) | .428 | .001 |
|                  | N              | 8   | 8   |
|                  | Pearson Correlation | .328 | 1 |
| Panel thickness  | Sig. (2-tailed) | .428 | 1.000 |
|                  | N              | 8   | 8   |
|                  | Pearson Correlation | .923* | .000 |
| Fiber content%   | Sig. (2-tailed) | .001 | 1.000 |
|                  | N              | 8   | 8   |

*aCorrelation is significant at the 0.01 level (2-tailed).

**Table 5.** The summary of the suggested model

|                | Adjusted R | Std. Error of the Estimate |
|----------------|------------|-----------------------------|
| Model          | R          | R Square                    | Square                      |
| 1              | .979*      | .959                        | .943                        | 1.33455                      |

*aPredictors: (Constant), Fiber content%, Panel thickness  
bDependent Variable: Ultimate load

**Table 6.** ANOVA test for the suggested model

|                | Sum of Squares | df | Mean Square | F    | Sig.  |
|----------------|----------------|----|-------------|------|-------|
| Model          |                |    |             |      |       |
| Regression     | 208.486        | 2  | 104.243     | 58.530 | .000b |
| 1              | 8.905          | 5  | 1.781       |      |       |
| Total          | 217.391        | 7  |             |      |       |

*bPredictors: (Constant), Fiber content%, Panel thickness  
aDependent Variable: Ultimate load
6. Conclusion

The following conclusion could be extracted from this study:

1- Using the steel fiber will improve the breaking load of the precast concrete panels and enhance its ductility. This will improve the handling and transportation process and reduce the spoilage of precast concrete panels.

2- Using 1% of steel fiber content will improve the ultimate load of the concrete panels up to 142% higher than plain concrete panels.

3- By using steel fiber volume fractions (0.25%, 0.5%, and 1%), it is possible to reduce the concrete panel thickness from 50 mm to 30 mm while achieving the ultimate breaking load as specified by the Iraqi standard specifications No.1107-87.

4- Incorporation of steel fiber in concrete panels’ production will provide an economic benefit to this production process due to reduce the raw materials consuming when reducing the panel thickness and the possible reduction in the spoilage upon handling and transportation.

5- The statistical analysis of the results approved the positive correlation between ultimate breaking load, and both steel fiber content and panel’s thickness.

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