University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering
journal homepage: www.jcoeng.edu.iq

Volume 30 Number 6 June 2024

Mechanical Properties of Lightweight EPS Self-compacting Concrete Reinforced with Steel Fibers

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ABSTRACT

This study aims to evaluate experimentally the mechanical characteristics of Self-Compacting Concrete (SCC) comprising expanded polystyrene beads (EPS) to produce flowable lightweight concrete reinforced with steel fibers. In this paper, the effect of steel fibers and EPS content on the fresh and hardened mechanical properties of SCC specimens, using two percentages for Polystyrene aggregate replacement (25% and 50%) and three values for volume fraction of steel fiber content (0%, 0.75%, and 1.5%), were examined. Fresh mixture properties were determined using slump flow, L-box, and V-funnel tests. Mechanical properties for hardened samples were obtained using standard specimens for compressive strength, density, split, and flexural strength. The study showed that EPS content has no adverse effect on the rheological features of the SCC. However, workability falls below specification limits when adding steel fibers to SCC. Results revealed that using 25% of EPS content resulted in lightweight structural concrete, while lightweight moderate-strength concrete was produced using 50% of EPS content. Furthermore, the study has shown that the split and flexural tensile strength were reduced substantially by 53% and 60% due to EPS addition. However, adding steel fibers remarkably improved the indirect tensile strength and Modulus of rupture by 46% and 80%, respectively. The mode of failure of the concrete specimens containing EPS beads and steel fibers did not show brittle failure behavior generally encountered in normal-weight concrete, indicating a more ductile behavior.

Keywords: Lightweight concrete, Expanded polystyrene (EPS), Self-compacted concrete, Steel fibers, Mechanical properties.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2024.06.08

Article received: 19/07/2023
Article accepted: 21/02/2024
Article published: 01/06/2024

الخواص الميكانيكية للخرسانة خفيفة الوزن EPS ذاتية الرص المعززة بألياف فولاذية

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الخلاصة

تهدف هذه الدراسة إلى دراسة الخواص الميكانيكية بشكل تجريبي للخرسانة ذاتية الرص المتضمنة لركام البولسترين لإنتاج خرسانة خفيفة الوزن وذاتية التدفق والرص(SCC) ومسلحة بألياف فولاذية. في هذا البحث، تمت دراسة تأثير محتوى الألياف الفولاذية والبولسترين (EPS) على الخواص الميكانيكية للخرسانية الطرية والمتصلبة لعينات SCC، باستخدام نسبتين مئويتين لاستبدال ركام البولسترين (25٪ و50٪) وثلاثة نسب مختلفة من الألياف الفولاذية (0٪ ،0.75 ٪ و1.5٪). تم تحديد خصائص الخليط الطري باستخدام ثلاث اختبارات (slump flow، L-box وV-funnel). وللحصول على الخواص الميكانيكية للعينات الصلبة تم استخدام عينات قياسية لقياس مقاومة الانضغاط، الكثافة، وقوة الشد ومقاومة الانحناء. أوضحت الدراسة أن محتوى البولسترين المتمدد (EPS) ليس له تأثير سلبي على الخواص الانسيابية للخرسانة ذاتية الرصSCC. ولكن، إضافة الألياف إلى SCC يقلل من قابلية التشغيل وتصبح دون حدود المواصفات. أوضحت النتائج أن استخدام 25٪ من محتوى EPS أدى إلى إنتاج خرسانة إنشائية خفيفة الوزن، بينما تم إنتاج خرسانة خفيفة الوزن متوسطة القوة باستخدام 50٪ من محتوى EPS. كشفت الدراسة أن تضمين EPS أدى إلى انخفاض في مقاومة الشد والانحناء بمقدار 53% و60%, على التوالي. ومع ذلك، فإن إضافة الألياف الفولاذية حسنت بشكل ملحوظ من قوة الشد والانحناء بمقدار 46% و80%, على التوالي. لم تظهر العينات الخرسانية المحتوية على حبيبات EPS والألياف الفولاذية سلوك فشل هش تتم مواجهته بشكل عام في الخرسانة ذات الوزن الطبيعي، مما يشير إلى سلوك أكثر مرونة.

الكلمات المفتاحية: خرسانة خفيفة الوزن، بولسترين ممدد، خرسانة ذاتية الرص، الياف فولاذية، الخصائص الميكانيكية

1. INTRODUCTION

Reusing and recycling waste materials is seen as the most environmentally friendly solution to the disposal problem. Therefore, a new approach to lightweight concrete production resembles the utilization of lightweight materials (agriculture and building waste materials and cork) as a replacement for aggregate (coarse or fine) **(Selman and Abbas, 2022; Abdullah et al., 2021)**. lightweight materials can be utilized as a whole or partial substitute to aggregate; hence, it is a new approach to producing lightweight concrete. Polystyrene (EPS) is a thermoplastic material that has the potential to be used in concrete for making lightweight concrete by replacing ordinary aggregate.

In recent years, EPS lightweight concrete has been utilized in constructing nonstructural and structural members such as walls and slabs due to its lightweight nature and beneficial thermal properties **(Liu and Chen, 2014; Mousavi et al., 2014). (Le Roy et al., 2005)** examined concrete's mechanical characteristics blended with cement matrix having high strength and EPS particles. They developed a model that relates concrete strength to EPS particle size and content. **(Miled, 2007)** illustrated that when the EPS percentage is high, the influence of EPS beads size on compressive strength has been decreased. **(Cook, 1972)** used

EPS beads as a substitute for coarse aggregates and the percentage of fine aggregates to create EPS concrete with seemingly less than 1400 kg/m^3 density and 3.0-10.0 MPa compressive strength. They explore the effect of the apparent density of EPS concrete on its compressive strength. **(Babu et al., 2006)** summarized the basis for the relationship between EPS concrete density and compressive strength through the conduction of experimental investigation and analysis of the findings for the proposed relationship. **(Gawale et al., 2016)** studied the concrete characteristics when EPS beads replaced the coarse aggregate. They discovered that lightweight EPS beads can be used to build partition walls and bed concretes. **(Cui et al., 2016)** replaced coarse aggregate with EPS beads to create EPS concrete with a dry density of 800-1200 kg/m^3. They proposed a stress-strain model for EPS concrete that corresponded well with the test findings. Because of its good energy-absorbing properties, it is practical to be used as a protective element in a building to withstand impact forces **(Bischoff et al., 1990).** They proposed that an overlaying layer of polystyrene concrete might protect structures from impact loading. They proposed a new polystyrene treatment approach to replace mineral aggregates with polystyrene. The authors investigated concrete creep and found that it is greater than conventional concrete **(Tang et al., 2014; Kan and Demirboga, 2009)**. **(Chen et al., 2010)** used expanded polystyrene beads instead of fine or coarse aggregate completely or partially to build an alternative lightweight concrete. The beads were in different sizes, with silica fume and polypropylene fibers added to enhance the concrete's properties. According to the results, there was an improvement in the bondage between polystyrene and cement paste when using silica fume in a certain amount. They also found that the polystyrene concrete strength was gradually reduced as the EPS content increased. **(Ewadh et al., 2012)** investigated the impact of using polystyrene beads in concrete on absorption and their workability. Polystyrene beads were used in various ratios for replacing sand or gravel (25, 50%, 75%, and 100%). They found that increasing the number of polystyrene beads increases the workability and absorption of concrete. For complete aggregate replacements with EPS beads, the absorption ability increased by 82%. Concrete tests indicated that whenever polystyrene granules were used in concrete with natural resin, density, thermal conductivity, and mechanical properties decreased while porosity increased **(Ayse and Filiz, 2016).** The strength of concrete with EPS beads influences and characterizes the overall qualities of polystyrene concrete because of the lower features of EPS beads, particularly density **(Salahaldeen and Al-Hadethi, 2022)**.

Mechanical properties of concrete can be enhanced commonly by adding fibers without impacting the concrete’s lightweight and low-density features due to fibers’ essential effect on the matter. Generally, fibers play an important role in the mechanical properties of concrete **(Salari et al., 2018; Alden and Al-Hadethi, 2023).** Fibers in lightweight concrete effectively prevented uncontrolled cracking due to shrinkage. Glass fibers resulted in multiple cracks and helped minimize crack width and, thus, improve ductility **(Mirza and Soroushian, 2016).** On the other hand, reduced workability, and increased cost due to adding large amounts of steel fibers were recorded by others **(Yao et al., 2003).** Lately, **(Abbas and Rakaa, 2023)** studied the structural performance of lightweight RC beams containing expanded polystyrene (EPS) and steel fibers. Different mixes were produced with (0%, 0.75%, and 1.5%) percentages of steel fibers, whereas 25% and 50% of EPS content were used. The results revealed that structural concrete using EPS could be produced and that steel fibers greatly enhanced the flexure strength of the tested beams. Furthermore, similar conclusions regarding structural lightweight EPS self-compacting concrete beams containing polyethylene terephthalate fibers were presented by **(Al-Hadethi et al., 2023).**

Researchers have become interested in employing EPS to replace coarse or fine aggregate in producing lightweight concrete in recent years. However, the majority of previous research in the literature concentrated on the mechanical characteristics of EPS concrete, both fresh and hardened.
Since EPS aggregate concrete has far fewer mechanical properties than conventional concrete, the primary goal of this work is to strengthen this form of lightweight concrete utilizing steel fibers. The following specimens were cast and tested to failure point to have the study's objectives achieved; fourteen cubical specimens (150x150x150) mm, fourteen cylindrical specimens (150x300) mm, and seven prism specimens (100x100x500) mm. The test results should give a clear understanding of the influence that the addition of EPS and steel fibers has on the concrete in terms of rheological properties, density, compressive and tensile strength, modulus of elasticity, and flexural strength.

2. EXPERIMENTAL PROGRAM

A set of standard test specimens were chosen to investigate the various parameters. The 28-day compressive strength was studied using (150x150x150) mm cubes. Tests on split tensile strength were performed on (150 x 300) mm cylindrical specimens. Flexural strength was measured using prisms measuring (100×100×500) mm. As illustrated in **Fig. 1**, the tested specimens were separated into three groups.

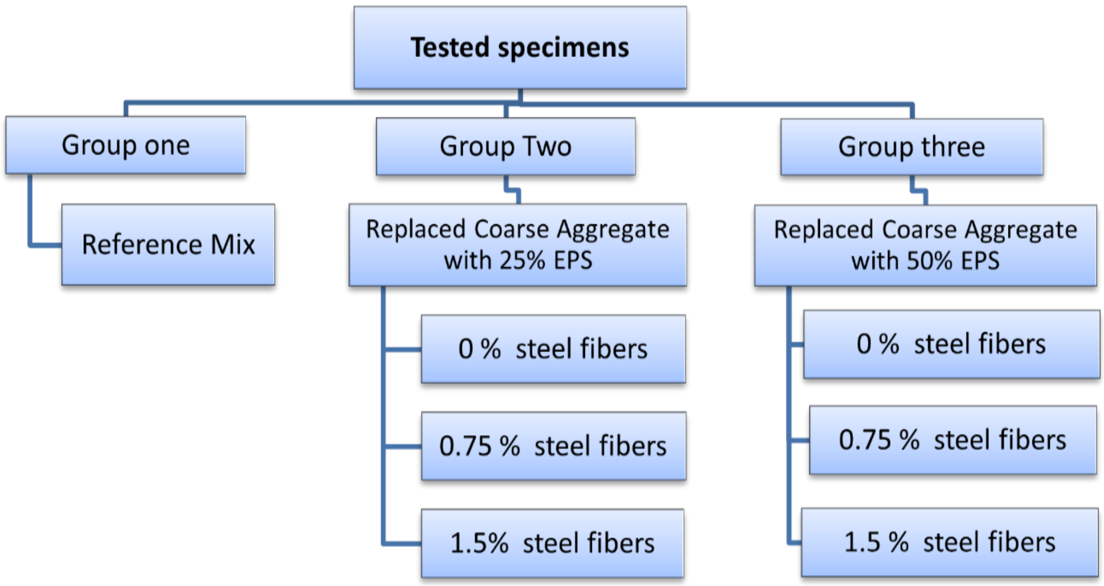


Figure 1. Experimental program details

2.1 Materials

In this study, EFNARC (**EFNARC, 2005**) specifications and guidelines for self-compacted concrete (SCC) were taken as reference for the mix design. Materials used to produce the SCC mixture included Portland cement, natural coarse and fine aggregates, silica fume (SF), and superplasticizer (SP). To accomplish low-density concrete in the experimental work, Expanded Polystyrene beads (EPS) were used to replace some percentage of the aggregate in the mixture comprising 25% and 50% of the volume fraction of the coarse aggregate. To enhance the strength characteristics of the final EPS mixture, different proportions of hooked steel fibers were used. The mechanical properties of steel fibers are shown in **Table 1,** while SCC materials composition and proportions for different mix designs are shown in **Table 2**. In all mixtures, 42 kg/m^3 of Silica fume, 375 kg/m^3 of cement content, and 44% of W/C ratio were used.

Table 1. Steel fiber's mechanical characteristics

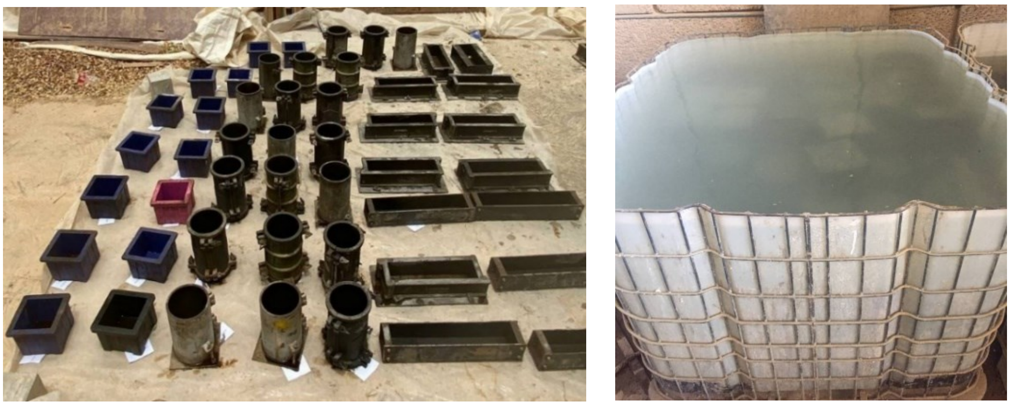
Fiber size, D (mm)	Length, L (mm)	Fiber aspect ratio (L/D)	Yield strength (MPa)
0.9	30	33.33	1900

Table 2. SCC mixtures composition and proportions for different mix designs.

Mix designation	EPS content, %	Steel fiber content, %	Sand (kg/m^3)	Gravel (kg/m^3)	EPS (kg)
R	0	0	746	992	0
E25 F0	25	0	746	744	1.284
E25 F75	25	0.75	746	744	1.284
E25 F150	25	1.5	746	744	1.284
E50 F0	50	0	746	496	2.568
E50 F75	50	0.75	746	496	2.568
E50 F150	50	1.5	746	496	2.568

2.2 Concrete Mixing and Casting

A mechanical pan-type mixer with a capacity of 0.25 m^3 was used to mix the concrete ingredients. First, 40% of water with SP was poured into the mixer, followed by dry EPS particles, and mixing proceeded for around two minutes to achieve a complete wetting of EPS particles with water and super-plasticizer. Then, the solid components were placed into the mixer, and 60% of the remaining water was consistently added. Finally, the fibers were evenly distributed throughout the mixture, and the mixing process was repeated for another two minutes. After that, fresh EPS lightweight concrete was cast into molds. A steel trowel was used to give the specimens leveled and fair-faced surfaces, as shown in **Fig. 2**.



(a) (b)

Figure 2. Specimens casting; (a) molds and (b) curing process.

2.3 Curing Process

Concrete cubes, cylinders, and prisms were de-molded after 24 hours of casting and moved to a water tank for 28 days of curing, as illustrated in **Fig. 2**.

3. RESULTS AND DISCUSSION

3.1 Fresh Concrete Tests

Several experimental mixes were attempted to produce SCC with a cube compressive strength of about 40 MPa. The mix proportions for mix designation R, listed in **Table 2**. represent a self-compacting concrete used as a reference mixture. Tests on slump flow time (T50) and maximum slump diameter, together with L-box and V-funnel flow time, were conducted to assess concrete mix rheological properties. To measure the flowability of SCC, generally, slump flow time and mixture dispersal area diameter are the most used methods **(Nagataki and Fujiwara, 1995).** In this test, the concrete starts to spread on the horizontal surface when the cone is lifted. The elapsed time for the mixture to freely flow and create a circle with a diameter of 50 cm is called the T50 time. The concrete's flow spread circle was measured at different points to record both slump-flow mean diameter and maximum diameter.

The results revealed that mixture R's slump flow time was 2s. According to EFNARC **(EFNARC, 2005),** the slump flow time for viscosity class VS1 must be $\leq 2s$. The slump flow diameter of 600mm was within the acceptable range for slump-flow class SF1 (550 - 650 mm) of EFNARC for reasonable RC structures cast from above. To evaluate the ability of the fresh mix to flow through confined spaces, the L-box test revealed a blocking ratio of 0.9 for mixture R, which confirms the accepted passing limits of EFNARC for passing ability ≥ 0.8 for classes PA1 or PA2. The measured V-funnel flow time of 7 s was within the limit of flow time class VF1$\leq$ 8s, according to EFNARC. All test results for mixture R indicated that the intended mixture is SCC concrete according to EFNARC, as indicated in **Fig. 3**.

The results of the slump-flow, T500 time, V-funnel flow time, and L-box tests for the mixtures when only coarse aggregate was replaced with EPS, i.e., E25 F0 and E50 F0, were also found in the acceptable ranges of EFNARC requirements, showing that EPS content has no adverse effect on the rheological properties of the SCC mixtures. On the other hand, adding steel fibers to the mixtures, i.e., E25 F0.75, E25 F1.5, E50 F0.75, and E50 F1.5, reduced the mixtures' workability below EFNARC limits. According to these results, there is an inverse relationship between the amount of steel fibers added to the mixture and the concrete's workability. Thus, the flowability of SCC with steel fibers through confined spaces was reduced.

(a) (b) (c)

Figure 3. SCC fresh concrete tests: (a) slump flow, (b) V-funnel flow, (c) L-box.

3.2 Hardened Concrete Tests

3.2.1 Density

Table 3. shows concrete density values for the different mixtures due to EPS and steel fiber content. According to ACI specifications **(ACI 318R, 2019)**, the reference concrete mixture's density of 2234.4 kg/m^3 is within the requirements for normal-weight concrete. The data summary in **Table 3** shows the drop in density percentage compared to normal concrete density through two groups of mixtures; group one has 25% EPS beads with 0%, 0.75%, and 1.5% of steel fibers for each mix, while group two has 50% EPS beads with the same proportions of steel fibers for each mix). Results indicated a decrease in the density for the first group in the range of 14.51% to 9.26% was recorded, whereas this decrease was in the range of 24.20% to 20.71% for the second group, according to the number of steel fibers used respectively. Concrete density values in **Table 3** indicated that concrete mixtures with EPS content, i.e., density values in the range of 1700.4-2035.6 kg/m^3, can be classified as lightweight concrete, even when unit weight slightly increased because of the inclusion of steel fibers **(ACI 213R, 2003**). In general, material density findings showed that when EPS was applied to the mix, the density rapidly dropped, whereas the addition of steel fibers enhanced unit weight.

Table 3. Concrete mixture density.

Mixture	Density (kg/m^3)	%variation	Mixture	Density (kg/m^3)	%variation
Group one			Group two		
R	2243.3	----	R	2243.3	----
E25 F0	1917.9	-14.51	E50 F0	1700.4	-24.20
E25 F75	1947.3	-13.19	E50 F75	1764.1	-21.36
E25 F150	2035.6	-9.26	E50 F150	1778.7	-20.71

3.2.2 Modulus of Elasticity

Understandably, the concrete's modulus of elasticity is directly related to its ingredient characteristics such as compressive strength, unit weight, aggregate type/content, and any changes in proportions in the mixture significantly affect the elastic modulus). Previous studies revealed a lower elastic modulus of SCC than that of normal-weight concrete with equivalent strength. On the other hand, other studies have shown a good correlation between the elastic Modulus of self-compacted concrete and that of conventional concrete, with comparable strength **(Persson, 1999).** In practice, the concrete Modulus is typically approximated from the concrete compressive strength using an empirical formula rather than testing. According to **(ACI 318R, 2019),** concrete Young's Modulus for values of w_c between 1440 and 2560 kg/m^3:

$$E_C = w_c^{1.5} 0.043\sqrt{f_c'} \tag{1}$$

where f_c': cylinder compressive strength, and w_c is the concrete unit weight.
For normal-weight concrete, concrete Young's Modulus:

$$E_C = 4700\sqrt{f_c'} \tag{2}$$

Values for the Modulus of elasticity for the concrete in the different mixtures tested in this study based on Equation 1 are illustrated in **Fig. 4**. Noting that mixture density in this study aggress well with the range of w_c applicable to Eq. (1) of the ACI. Results showed that concrete Young's Modulus significantly decreased due to EPS content, whereas steel fibers addition slightly helps recover its values. This is attributed to the concrete's low density or unit weight in the tested samples due to the EPS replacement of coarse aggregate.

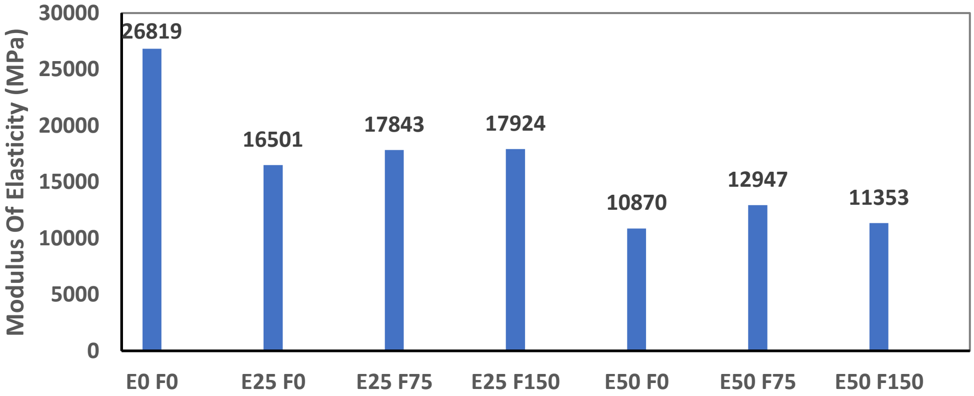


Figure 4. Modulus of Elasticity for concrete mixtures.

3.2.3 Compressive Strength

Various sizes of concrete specimens were used depending on the required parameter, so, for the compressive strength evaluation, the specimen was 150 mm cubes tested 28 days after casting. Compressive strength was experimentally evaluated using fourteen cube specimens tested according to B.S 1881: part 116 **(BS 1881-116, 1983).** Compressive test results for 28 days are compiled in **Table 4** and presented in **Fig. 5**.

Table 4. Tested 28-day cube compressive strength records.

Mixture	f_c' (MPa)	%variation	%variation due to steel fibers
Group one			
R	34.5	----	
E25 F0	20.9	-39.4	----
E25 F75	23.3	-32.5	11.5
E25 F150	20.6	-40.3	-1.40
Group two			
R	34.5	----	
E50 F0	13.0	-62.3	----
E50 F75	16.5	-52.2	26.9
E50 F150	12.4	-64.0	-4.60

A compression machine with a capacity of 2000 kN, at the Consulting Engineering Bureau at the University of Baghdad, was used to perform these testing. **Fig. 6** shows the testing machine with the failure mode for the cube sample. The compressive strength result was determined by taking the average value of two tested specimens for each mix. The cylinder's compressive strength, f_c', has been correlated to the cube's compressive strength, f_{cu}, based on the following relation:

$$f_c' = \frac{4}{5} f_{cu} \tag{3}$$

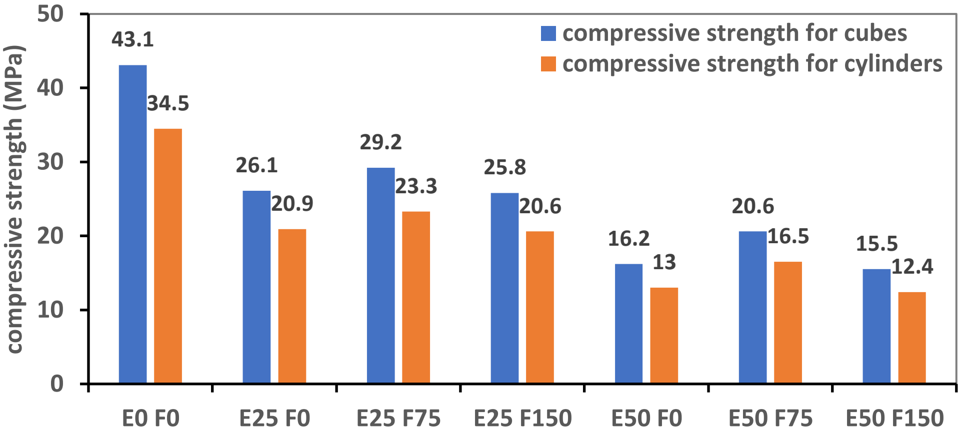


Figure 5. Compressive strength of concrete specimens.

The test findings showed that adding EPS resulted in a significant reduction in compressive strength, whereas adding steel fibers resulted in a relatively small rise. Also, it was revealed that raising the proportion of steel fibers by a particular amount has a negative impact on compressive strength because it causes a reduction in compressive strength. **Table 4** shows the variation in the compressive strength records concerning EPS and steel fiber proportions. It is observed that a reduction of about 40% in the compressive strength was achieved due to 25% of EPS content, whereas this reduction raised to 62% due to 50% of EPS replacement. Also, adding 0.75% steel fibers volume fraction improved EPS concrete compressive strength by 11.5% and 27% for groups one and two, respectively. The slight increase in the compressive strength is attributed to the bridging effect of adding steel fibers. On the other hand, data shows that increasing steel fibers volume fraction from 0.75% to 1.5% causes a reduction in the compressive strength by 1.4% and 4.6% in groups one and two, respectively, compared to reference mix concrete. Higher steel fiber concentration reduces SCC workability and filling ability, which leads to lower compressive strength, **(Khaloo et al., 2014; Abdalla, 2021).**

(a) (b)

Figure 6. Compressive strength test; (a) testing machine; (b) test cube failure.

Lastly, according to the results, lightweight structural concrete with $f_c' \geq 17$MPa was achieved using 25% EPS concentration, while lightweight moderate-strength concrete with $7 \leq f_c' \leq 14$ MPa was achieved using 50% EPS concentration, **(ACI 213R, 2003).** The compressive failure of the concrete cubes containing EPS aggregates and steel fibers showed a large deformability before failure. It did not exhibit the typical brittle failure normally associated with normal-weight concrete.

3.2.4 Splitting Tensile Strength

Split tensile strength tests were conducted on fourteen standard cylinder specimens of 150 x 300 mm size at 28 days following **(ASTMC496/C496M, 2017).** Splitting tensile strength results were determined by taking the average value of two tested specimens for each mix. This test was carried out using a compression testing machine with a capacity of 2000 kN. The load was applied diametrically along the length of the specimens till reaching failure, as shown in **Fig. 7**. The test was conducted at the Consulting Engineering Bureau at the University of Baghdad. Splitting tensile strength (f_t) was evaluated using the following formula:

$$f_t = {}^{2P}/_{\pi l d} \tag{4}$$

where:
f_t: split concrete tensile strength in (MPa) units,
P: ultimate testing load in (N) units,
d: measured testing cylinder diameter in (mm) units,
l: measured testing cylinder length in (mm) units.

(a) (b)

Figure 7. Splitting tensile strength test; (a) testing machine; (b) testing cylinder failure.

Fig. 8 below shows the tensile strength test records for each specimen. The variation of tensile strength concerning EPS and steel fiber concentrations is shown in **Table 5**. The test results demonstrated that splitting tensile strength significantly reduced when adding polystyrene beads EPS. However, a significant impact has been noticed due to steel fiber addition, causing a substantial increase in the splitting tensile strength. Results showed that EPS content reduces split tensile strength by 36.5% and 53% due to 25% and 50% of EPS content, respectively. On the other hand, adding 1.5% of steel fibers restores tensile strength up to 46.5% and 31.8% for groups one and two, respectively, indicating the most efficient steel fiber effect for lower EPS content.

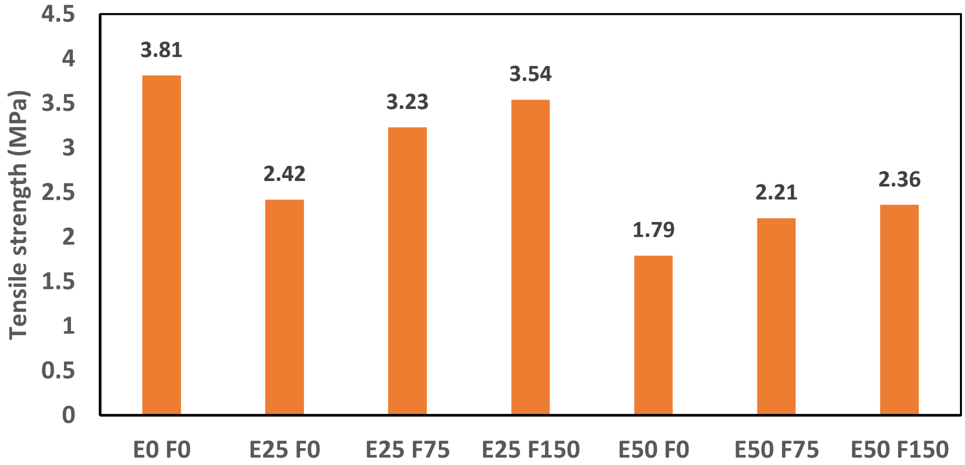


Figure 8. Split tensile strength of concrete specimens at 28 days.

Table 5. 28 days split tensile strength test records.

Mixture	f_t (MPa)	%variation	%variation due to steel fibers
Group one			
R	3.81	----	
E25 F0	2.42	-36.5	----
E25 F75	3.23	-15.2	33.5
E25 F150	3.54	-7.1	46.3
Group two			
R	3.81	----	
E50 F0	1.79	-53.0	----
E50 F75	2.21	-42.0	23.5
E50 F150	2.36	-38.1	31.8

3.2.5 Flexural strength (modulus of rupture)

According to ASTM C 78-2002 **(ASTM C78, 2002),** the modulus of rupture was measured by testing (100×100×500) mm prism specimens**.** The prisms were subjected to mid-span point loading using a flexure testing machine. The tests were carried out at the Consulting Engineering Bureau at the University of Baghdad, as shown in **Fig. 9**. Test results showed that cracking started at the tension face of the prism at mid-span length. Hence, the modulus of rupture (f_r) calculated as follows:

$$f_r = {}^{3PL}/_{2bd^2} \tag{5}$$

where f_r is the flexure stress (MPa), P is the maximum load (N), b is the prism width (mm), d is the prism depth (mm), and L is the span length for loading (mm).
According to **(ACI 318R, 2019)**, the modulus of rupture (f_r) can be calculated using Eq. (6) below:

$$f_r = 0.62\lambda\sqrt{f_c'} \tag{6}$$

where: λ = reduction factor (1.0 for normal weight concrete, 0.75 for lightweight concrete)

(a) (b)

Figure 9. Flexural strength test; (a) testing machine; (b) failure of tested prisms.

Test results of prism samples are given in **Table 6** and illustrated in **Fig. 10.**

Table 6. 28 days flexural strength test records.

Mixture	f_r (MPa)	%variation	%variation due to steel fibers
Group one			
R	4.70	----	
E25 F0	4.13	-12.1	----
E25 F75	4.79	1.9	16.0
E25 F150	4.85	3.2	17.4
Group two			
R	4.70	---	
E50 F0	2.41	-48.7	----
E50 F75	3.69	-21.4	53.1
E50 F150	4.34	-7.7	80.1

Research findings showed that the modulus of rupture significantly decreased with the addition of EPS particles, and the reduction was about 12% and 49% for EPS content of 25% and 50%, respectively. Moreover, adding steel fibers remarkably improved the modulus of rupture. As presented in Table 6, for moderate EPS content in group one, results revealed that adding 1.5% steel fiber volume fraction causes an increase of 17.4% in the flexural strength, whereas, for high EPS content in group two, adding the same amount of steel fibers causes 80% increase in the modulus of rapture. These results are like the findings of previous researchers **(Khaloo et al., 2014; Abdalla et al., 2021)**. Results in **Fig. 10** also presented the predicted values for the modulus of rupture according to the **(ACI 318R, 2019)** code expression given by Eq. (6) with the appropriate lightweight concrete reduction factor. By comparing the experimental results with the ACI code formula data, it is demonstrated that there is a clear underestimation in the flexural strength of EPS concrete reinforced with steel fibers.

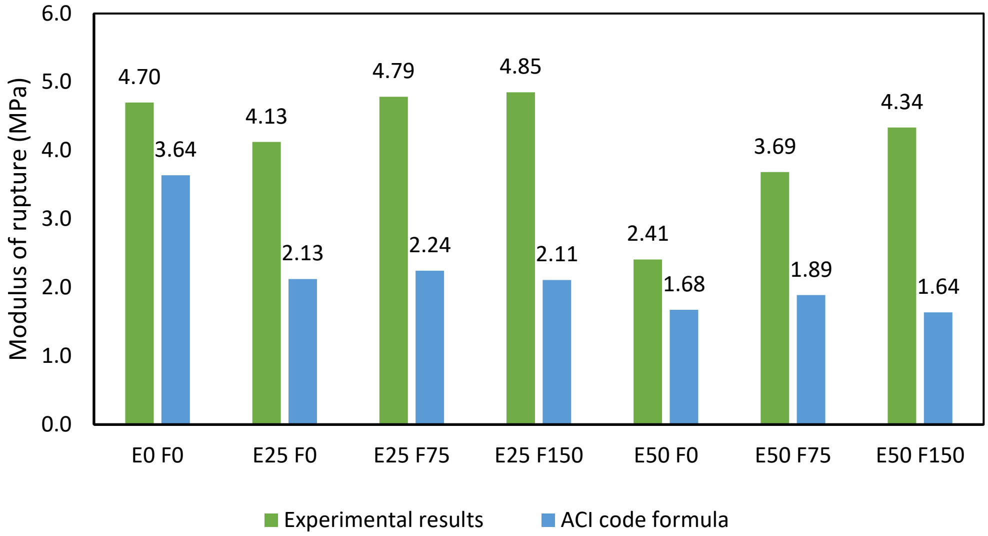


Figure 11. Flexure strength of concrete specimens.

4. CONCLUSIONS

According to experimental findings, discussions, and presented results, the achieved conclusions are summarized in the following points:

1. Results showed that EPS content has no adverse effect on the rheological characteristics of SCC. On the other hand, when steel fibers were added, workability fell below specification limits, indicating reduced flowability for SCC with fibers through confined spaces.
2. Density results illustrated that when EPS is utilized, the density rapidly decreases, and the addition of steel fibers helps to increase the density. Generally, EPS concrete with steel fibers can be classified as lightweight concrete.
3. Test findings showed that compressive strength is reduced substantially when adding EPS beads. A 40% and 62% reduction in compressive strength was achieved due to 25% and 50% of EPS content, respectively. However, adding steel fibers resulted in a relative enhancement in the compressive strength for 0.75% steel fiber content. However, using 1.5% steel fiber content resulted in an adverse effect.
4. Applying 25% coarse aggregate replacement with EPS in the mix resulted in a lightweight structural concrete. while using 50% EPS bead replacement in the concrete mixture produces moderate-strength lightweight concrete.
5. Results showed that split tensile strength is reduced substantially when adding EPS beads, while steel fibers have an important constructive impact on the splitting tensile strength. Adding 1.5% of steel fibers restores tensile strength up to 46.5% and 31.8% for mixtures with 25% and 50% of EPS content, respectively.
6. Flexure strength tests revealed that the modulus of rupture decreased by 12% and 49% for EPS content of 25% and 50%, respectively. However, the modulus of rapture is significantly improved when using higher steel fiber content, hence for 50% EPS lightweight concrete the modulus of rapture was recorded to be 53% and 80% higher when using 0.75% and 1.5% steel fibers content, respectively.

NOMENCLATURE

Symbol	Description	Symbol	Description
ASTM	American society for testing and materials	SCC	self-compact concrete
E_c	concrete Young's modulus, MPa	f_c'	concrete cylinder compressive strength, MPa
EFNARC	European federation for specialist construction chemicals and concrete systems	f_{cu}	concrete cube compressive strength, MPa
EPS	expanded polystyrene	f_r	concrete flexure strength, MPa
L	span length for loading, mm	f_t	concrete split strength, MPa
l	testing cylinder length, mm	λ	Lightweight reduction factor

Acknowledgments

This work was supported by the Department of Civil Engineering, College of Engineering, University of Baghdad. The authors are grateful for this support which significantly facilitated this study.

Credit Authorship Contribution Statement

Rawah Khalid Rakaa: Writing – review & editing, Writing – original draft, Investigation, Experimental work, Resources. Rafaa Mahmood Abbas: Writing – review & editing final draft, Supervision, Methodology, Validation, Results analysis, Reviewing & support.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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