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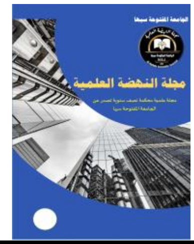

"Evaluation of the Mechanical Properties of Normal Concrete Reinforced with Steel Fibers Recovered from used Tires"

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Abstract

This study investigated the effect of incorporating recycled steel fibers from waste tires on the mechanical and physical properties of concrete in both fresh and hardened states. Steel fibers with a diameter of 1 mm and lengths ranging from 15–25 mm were added at different mixing ratios (0.25%, 0.50%, 0.75%, and 1.00%), with results compared to a reference mix containing no fibers. Tests were conducted to evaluate workability (slump) and fresh density in the plastic state, as well as compressive strength, splitting tensile strength, flexural strength, and ultrasonic pulse velocity after 28 days of curing.

The results indicated a reduction in workability and fresh density with increasing fiber content, while no significant changes were observed in compressive strength. In contrast, a notable improvement was recorded in splitting tensile strength (21% increase at 1% fiber content) and flexural strength (34% increase) compared to the reference mix. Ultrasonic testing further confirmed enhanced homogeneity in the fiber-reinforced concrete. These findings highlight the potential of recycled steel fibers in improving concrete performance, particularly in resisting tensile stresses and cracking.

Keywords: Steel fibers, Waste tire utilization, Mechanical properties, Sustainable construction, Concrete

تقييم الخواص الميكانيكية للخرسانة العادية المعززة بألياف فولاذية مستخلصة من الإطارات المستهلكة

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الملخص

هدفت هذه الدراسة إلى تقييم تأثير إضافة الألياف الفولاذية المستخلصة من إطارات السيارات المستهلكة على الخصائص الميكانيكية والفيزيائية للخرسانة في حالتَيها اللدنة والمتصلدة. استُخدمت ألياف فولاذية بأقطار 1 ملم وأطوال تتراوح بين 15–25 ملم، وبنسب خلط مختلفة (0.25%، 0.50%، 0.75%، 1.00%)، مع مقارنة النتائج بخلطة مرجعية خالية من الألياف. شملت الاختبارات تقييم قابلية التشغيل (هبوط الخرسانة) والكثافة الطرية في الحالة اللدنة، إضافة إلى اختبارات مقاومة الانضغاط، والشد الانشطاري، والانحناء، والموجات فوق الصوتية بعد 28 يومًا من التصلد.

أظهرت النتائج انخفاضًا في قابلية التشغيل والكثافة الطرية مع زيادة نسبة الألياف، بينما لم تُسجل تغيرات كبيرة في مقاومة الانضغاط. في المقابل، لوحظ تحسن ملحوظ في مقاومة الشد الانشطاري بنسبة 21% عند إضافة 1% من

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الألياف، وكذلك في مقاومة الانحناء بنسبة 34% مقارنة بالعينة المرجعية. كما كشفت نتائج اختبار الموجات فوق الصوتية عن تحسن في تجانس الخلطة الخرسانية بعد إضافة الألياف. تُبرز هذه الدراسة إمكانية الاستفادة من الألياف الفولاذية المستخلصة في تعزيز أداء الخرسانة، خاصة في تحمل إجهادات الشد والتشققات.

الكلمات المفتاحية: ألياف الفولاذ، الإطارات المستعملة، الخصائص الميكانيكية، البناء المستدام، الخرسانة.

1. Introduction

With the significant increase in the number of cars in Libya and the rising import of used tires, which often have a remaining lifespan of less than half their expected duration, a major problem has emerged regarding the disposal of worn-out tires. These tires are often discarded randomly on roads or burned, resulting in the release of large amounts of polluted smoke. This pollution not only affects air quality and public health but also contributes to exacerbating climate change and poses a threat to the ozone layer. [1]

In response to these environmental challenges, we decided to invest in these waste materials in an innovative and sustainable way. Our idea is to extract the steel fibers found in the tires and reuse them in concrete mixes. This solution aims to reduce the accumulation of tires and to utilize their resources effectively, without leaving any negative environmental impact. This initiative not only provides a solution to the waste problem but also contributes to improving the quality of concrete mixes and enhancing the sustainability of the construction sector in Libya.[1]

In modern times, a wide variety of steel fibers are used worldwide, with excessive increase. The global tire consumption rate in 2023 was 2.3 billion units, and it is expected to reach 2.7 billion units by 2028. Comparing concrete reinforced with steel fibers extracted from consumed car tires with traditional steel fiber-reinforced concrete shows that it is a candidate for use in engineering applications.[4]

Studies have shown that concrete reinforced with recycled metallic fibers has promising applications in various engineering fields. It is effectively utilized in industrial flooring to reduce damage caused by wear and impact, as well as in machine foundations to mitigate the effects of vibrations and dynamic loads. Additionally, it can be employed in the construction of roads and airport runways, serving as a base layer to minimize cracking and enhance structural performance. [2]

The addition of steel fibers to reinforced concrete can significantly enhance multiple engineering properties, including fracture toughness, flexural strength, fatigue resistance, impact resistance, and abrasion resistance. When these enhanced properties - along with the inherent advantages of fiber reinforcement - are properly utilized in construction or manufacturing technologies, they offer substantial improvements. Steel fibers effectively reduce crack width propagation in concrete and promote more uniform crack distribution. Their most critical function is dramatically increasing the concrete's toughness modulus, thereby altering the failure mechanism from sudden and dangerous brittle fracture to gradual, ductile failure.[3]

2. Experimental work

The experimental work initially relied on conducting tests on the raw materials, followed by experimental mixtures to achieve a mix with good properties, both in the fresh and hardened states.

2.1 Materials

2.1.1 Cement

Ordinary Portland cement (Beni-Suef Military N 42.5) imported from Egypt, manufactured in Beni-Suef Governorate, was used. Table (1) shows the physical and mechanical properties, noting that it complies with British specifications.[5]

Table (1): Physical and mechanical Properties of Cement

Test	Result
Cement Fineness	8.57%
Initial Setting Time	120 minutes
Final Setting Time	210 minutes
Compressive Strength (3 days)	23.03 N/mm²
Compressive Strength (28 days)	44.87 N/mm²

2.1.2 Coarse Aggregate:

In this study, graded coarse aggregate with nominal sizes of (5–10) mm and (10–20) mm was used in a ratio of 1:1.5. The aggregate was sourced from a crusher located in the city of Al-Abyar. Table (2) presents the physical and mechanical properties of the aggregate, while Table (3) shows the particle size distribution (gradation) of the aggregate. The results confirmed that the aggregate complies with the British Standard.[6,7,8,9,10]

Table (2): Physical and Mechanical Properties of Aggregate

Test	Aggregate Size (5–10) mm	Aggregate Size (10–20) mm
Specific Gravity	2.38	2.37
Water Absorption	1.90 %	1.30 %
Impact Value	20.58 %	
Crushing Value	33.30 %	

Table (3): Particle Size Distribution of Aggregate

Sieve Size (mm)	20	14	10	5	2.36

Passing (%)	99.05	73.25	41.80	3.40	0.05

2.1.3 Fine Aggregate

For this study, natural sand was used as fine aggregate, sourced from the Sultan area. The sand was sun-dried for 7 days before use. Table (4) presents the particle size distribution (gradation) of the fine aggregate with the British Standard.[7]

Table (4): Particle Size Distribution of Fine Aggregate

Sieve Size (mm)	5.00	2.36	1.18	0.6	0.3	0.15
Passing (%)	100	99.95	99.05	88.90	72.45	0.9

2.1.4 **Mixing Water**

Ordinary potable water was used to prepare the concrete mixtures.

2.1.5 **Steel Fibers**

Steel wires extracted from used car tires were used, with lengths ranging from 15 to 25 mm and a diameter of 0.6 mm. The fibers were added to the dry mix before the addition of water.

Figure (1): **Steel Fibers**

3. Casting, Mixing, and Curing Process

After conducting several trial mixes, the suitable concrete mix was determined with a ratio of 1:2:4 and a water-to-cement ratio (W/C) of 0.6. The mixing process was carried out at the Civil Engineering Laboratory at the University of Benghazi. Coarse aggregate, cement, and fine aggregate were placed in the lab mixer and dry mixed for 30 seconds. Then, the steel fibers were added all at once, and mixing continued for two minutes while water was gradually added.

After mixing and conducting fresh concrete tests, the mixture was transported and cast into molds within a short time. The molds were pre-lubricated with oil to prevent the specimens from sticking. A mechanical vibration table was used to compact the concrete, with a compaction time of 6 seconds.

Five concrete mixes were designed. The first mix was the reference mix (without steel wires), and the remaining mixes included steel fibers at rates of 0.25%, 0.50%, 0.75%, and 1% of the total concrete mix weight, respectively.

For each mix, three cubes of 100x100x100 mm, three cylinders of 100x200 mm, and two prisms of 500x100x100 mm were cast to determine compressive strength, splitting tensile strength, and flexural strength, respectively, according to British Standards[13,14,15]. The total number of specimens was 15 cubes, 15 cylinders, and 10 prisms.

After casting and surface finishing, the samples were left at room temperature in the lab for 24 hours. Then, the molds were removed, the samples were labeled, and they were submerged in a water tank for curing for 27 days. Table (5) shows the material quantities for the concrete mixes.

Table (5): Material Quantities for Concrete Mixes

Mix No.	No. of Specimens	Fiber Ratio (%)	Fiber Weight (kg)	Cement Weight (kg)	Coarse Aggregate Weight (kg)	Fine Aggregate Weight (kg)	Water Volume (L)
					(5–10 mm)	(10–20 mm)	
1	8	0	0.000	6.40	10.24	15.36	3.84
2	8	0.25	0.122	6.40	10.24	15.36	3.84
3	8	0.50	0.243	6.40	10.24	15.36	3.84
4	8	0.75	0.365	6.40	10.24	15.36	3.84
5	8	1.00	0.486	6.40	10.24	15.36	3.84

Figure (2): Curing of the samples

4. **Laboratory Tests**

4.1 Fresh Concrete Tests

The Slump Test and fresh concrete density test were conducted according to British Standards [11,12]

4.2 Hardened Concrete Tests

Compressive strength, splitting tensile strength, and flexural strength tests were conducted at 28 days in accordance with British Standards.[13,14,15]

5. Results and Discussion:

5.1 Workability

The slump test readings showed a difference between the reference sample (without steel fibers) and the other samples containing steel fibers. It was found that as the fiber content increased in the concrete mix, the slump (workability) decreased compared to the reference sample. The slump decreased by a rate ranging from 17.14% to 90%. This reduction is attributed to the clustering of the concrete mix components around the steel fibers. Table No. (6) shows the slump values of the concrete mixes.

Table (6): Slump Test Results

Mix No.	Fiber Content (%)	Slump Value (mm)
1	0.00	70
2	0.25	58
3	0.50	53
4	0.75	21
5	1.00	7

Figure (3): Slump Test

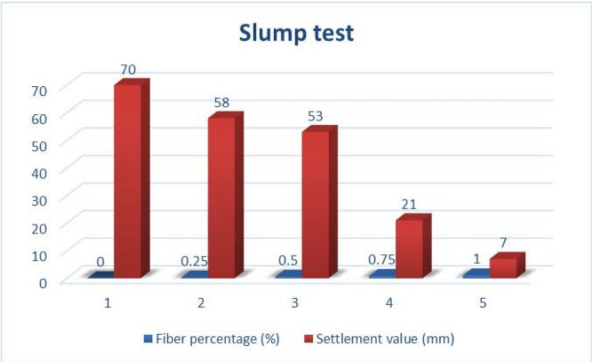

Figure (4): Slump Test Results

5.2 Fresh Density

When determining the fresh density [12] A slight decrease in the fresh density of concrete was observed with the increase in the proportion of steel fibers. This is attributed to the entrapment of fine air voids resulting from the shape, size, and length of the fibers, which leads to particle dispersion and the formation of micro-voids within the mix. Although steel fibers are added in small weight percentages, they occupy a relatively larger volume compared to their weight, resulting in a partial replacement of higher-density components, such as aggregates, and consequently a reduction in the overall density of the concrete mix. Table (7) shows this.

Table (7): Fresh density

Mix No.	Fiber Content (%)	Density (kg/m³)
1	0.00	2470
2	0.25	2402
3	0.50	2327
4	0.75	2166
5	1.00	2101

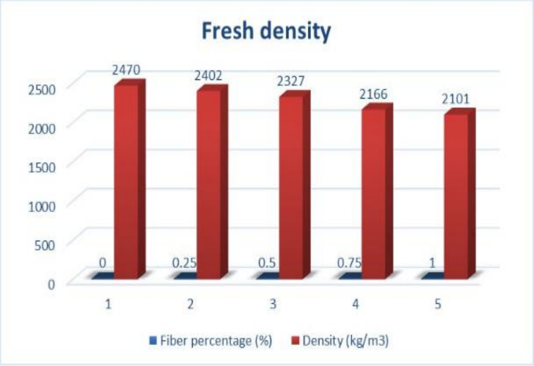

Figure (5): Fresh density Results

5.3 Compressive Strength

Compressive strength tests were performed on concrete cubes. Results showed a slight decrease in compressive strength for the mixes containing steel fibers compared to the reference sample (without fibers). The compressive strength decreased as the fiber content increased, with a reduction range between 5.73% and 9.40%. Table 7 shows the effect of fibers on compressive strength.[13]

Table (8): Compressive Strength Results

Mix No.	Fiber Content (%)	Compressive Strength (N/mm²)
1	0.00	43.6

2	0.25	41.1
3	0.50	41.0
4	0.75	39.7
5	1.00	39.5

Figure (6): Fresh density Results

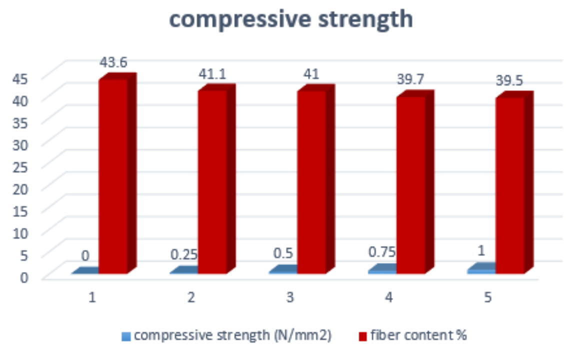

Figure (7): Compressive Strength Results

5.4 Tensile Strength

The indirect tensile test, commonly referred to as the "Brazilian test," is a standardized method used to estimate the tensile strength of concrete in an indirect manner, due to the practical difficulties associated with direct axial tension testing of brittle materials. In this test, a cylindrical concrete specimen (with a diameter of 100 mm and a height of 200 mm) is diametrically loaded between two steel platens such that a compressive force is applied along the vertical diameter of the cylinder.

Although the applied load is compressive, the specimen experiences horizontal tensile stresses at its center, which eventually lead to splitting along the vertical diameter. This failure mechanism provides a measure of the material's tensile strength. The indirect tensile strength is calculated using the standard formula specified in relevant testing standards [14], based on the maximum applied load and the specimen dimensions

The test was conducted on standard cylindrical specimens (100 × 200 mm) at 28 days for 15 samples. The results showed that the tensile strength increased with the rise in fiber content. Compared to the reference sample, the increase reached 21.34%. Table 9 shows the results of the tensile strength test.[14]

Table (9): Tensile Strength Results

Mix No.	Fiber Content (%)	Splitting Tensile Strength (N/mm²)
1	0.00	2.53
2	0.25	2.65
3	0.50	2.94

4	0.75	2.98
5	1.00	3.07

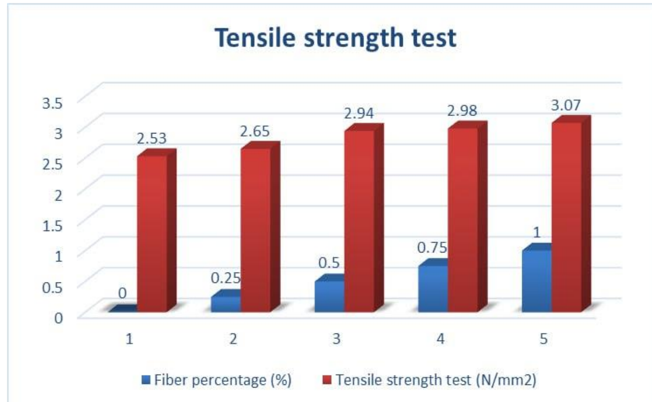

Figure (8): Tensile Strength Test

Figure (9): Tensile Strength Results

5.5 Flexural Strength

Flexural strength tests were conducted on 10 specimens (500 × 100 × 100 mm). The results showed that the flexural strength increased with the fiber content when compared to the reference sample. Table 10 presents the results of the flexural strength test.[15]

Table (10): Flexural Strength Results

Mix No.	Fiber Content (%)	Flexural Strength (N/mm²)
1	0.00	4.60
2	0.25	5.50
3	0.50	5.80
4	0.75	6.00
5	1.00	6.20

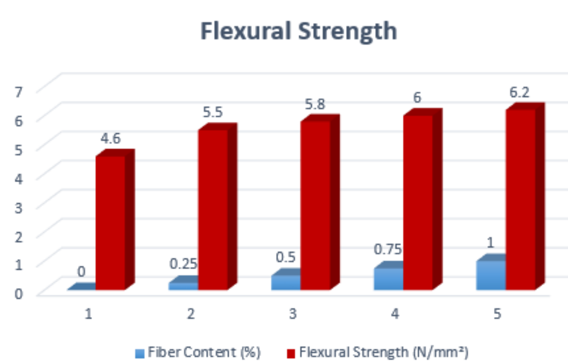

Figure (10): Two Point Bending Test

Figure (11): Bending Test Result

5.6 Ultrasonic Pulse Velocity Test

Ultrasonic pulse velocity tests on the cubes showed a slight reduction in wave speed as the steel fiber content increased. This is attributed to the steel wires creating small air voids within the mix. Table 11 shows the ultrasonic pulse velocity results.

Table (11): Ultrasonic Pulse Velocity Results

Mix No.	Fiber Content (%)	Ultrasonic pulse velocity (km/s)
1	0.00	5.00
2	0.25	5.13
3	0.50	5.13
4	0.75	5.24
5	1.00	5.32

Figure(12): Ultrasonic Pulse Velocity Test

6. Conclusions

1. Fresh density shows a gradual and slight decrease, which can be attributed to the length and shape of the steel fibers causing particle dispersion and the formation of small voids.
2. Workability decreases with increased fiber content. The slump value dropped by 17.14% to 90%, compared to the reference sample, due to the tendency of the mix components to gather around the steel fibers.
3. Compressive strength decreases slightly as fiber content increases. In contrast, splitting tensile strength increases with higher fiber content, with a maximum improvement of 21.34% over the reference mix. This is because steel fibers enhance bonding between the components (aggregate, cement paste) and reduce stress concentration.
4. Flexural strength increases with higher steel fiber content in concrete beams, reaching up to 35% improvement compared to the reference mix without fibers.
5. Incorporating steel fibers extracted from waste vehicle tires in concrete production helps reduce harmful waste, lower costs, and conserve natural resources.

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