JOURNAL OF MARINE SCIENCES & ENVIRONMENTAL TECHNOLOGIES
Vol. 7, Issue No. 2 (December-2021)

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Compressive Strength Improvement of Lightweight Concrete by Incorporation Waste Materials: An Experimental Investigation

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دراسة عملية لتحسين مقاومة الضغط للخرسانة العادية بإضافة مخلفات المواد (دبابيس)

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Received: 04 September 2021; Revised: 01 October 2021; Accepted: 28 October 2021.

Abstract

In the world of depletion of resources, using recycled materials is getting more and more interesting, since recycling generally reduces the need for extracting, refining, and processing raw materials. In this study, attempts to investigate the effect of two types of steel fibers (staples) on concrete compressive strength have been experimentally accomplished. The different fibers at constant fractions of 0.5%, 1%, 1.5%, and 2 % by the weight of cement are used as reinforced agents with different curing duration times of steel fibers-normal concrete samples. The results obtained by the compressive strength test showed a significant improvement in the concrete compressive strength up to 47.8 MPa could be on hand with such simple reinforcement.

Keywords: *Compression strength, Staples, Steel fibers.*

الملخص

أصبح استخدام المواد المعاد تدويرها يلقى اهتماماً كبيراً في العالم، لأنها تقلل بشكل عام من الحاجة لإستخراج المواد الخام وتكريرها ومعالجتها. في هذه الدراسة تم إجراء الاختبارات لدراسة تأثير نوعين من الألياف الفولاذية (الدبابيس) على مقاومة الضغط للخرسانة، حيث تم إضافة الألياف الفولاذية إلى الخرسانة بنسب (0.5، 1، 1 و 2%) من وزن الإسمنت. وتم معالجة العينات بالغمر في الماء واختبارها بعد (7 و 14 و 28) يوم، حيث أظهرت نتائج العينات تحسناً ملحوظاً في مقاومة الخرسانة للضغط تصل إلى (47.8 ميجا باسكال) مقارنةً بالخرسانة العادية (41.24 ميجا باسكال). نستنتج من الدراسة أنه يمكن استخدام مواد بسيطة مثل (الدبابيس) من خلال إعادة تدويرها في تعزيز مقاومة الضغط للخرسانة.

الكلمات الدالة: قوة ضغط الخرسانة، الدبابيس، الألياف الفولاذية.

1. Introduction

Recently, combinations of two or more different materials to form a composite material with enhanced properties have been growing rapidly. It is difficult to find a field of technology for everyday life immune to this type of material used. Composites are widely used in civil

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

engineering and the most common application is lightweight concrete. Many important constructions are fabricated from various composite materials nowadays. Ensuring a high concrete performance with unique and exceptional properties compared with ordinary concrete that uses traditional materials, could be obtained by unusual combinations of distinct materials using modern ways and techniques of mixing. Composite materials are stronger, lighter, and less dense than single-phase materials due its combination and mixing. There is no chemical reaction between the mixture and each material's basic properties are maintained, but these materials support each other as a kind of teamwork. Concrete is a composite material in which basic materials such as sand, gravel, and cement are mixed in order to achieve a certain performance. Lightweight concrete whose main component is mortar mixed with at least 20% of air volume and additional materials, has a history and patent in 1923. Years later, trends of using natural materials associated with the environment in concrete and constructions have been developed, and the most important example is green building systems which aims to start the natural world with a good life (Kamal *et al.*, 2014). In addition, building materials, recycling, and disposal of waste materials such as rubber and polymer material can be integrated with lightweight flexible materials for a wide range of purposes such as wall molding, floor and ceiling, full molding of home, walls of sound barrier including control of density, and compressive strength in super concrete technology as a result of more than 20 years product tuning and searching for possible applications. It is used in more than 40 countries around the world today and has not reached the end of its potential uses. Therefore, there is a need to understand and study different types of new recycling materials that could be used in concrete to implement optimized techniques that will avoid defects and give apposite self-sustaining, durable composite material that is efficient for the desired in sustainable construction materials and the building is environmentally friendly (Behbahani and Nematollahi, 2011).

Performed an experimental study on a discontinuous and randomly oriented steel fiber-reinforced concrete matrix at different aspect ratios and constant rate of 2.5% by the weight of cement of the steel fibers, and investigated how that affects the concrete strength in terms of its compressive and bending resistance. The results indicated a positive effect of such reinforcement and showed significant improvements in the aforementioned strength using steel fibers with a variety of aspect ratios and volume fractions (Dahake, 2016). Examined experimentally a lightweight concrete compressive strength by adding steel scrap wires with different volume fractions. They found that the addition of the scrap steel wires up to a 0.5% volume fraction increases the concrete compressive strength, and that will lead to lower it at any value more than 0.5% of reinforcement. Concrete in general is a brittle material with low tensile strength and strain capacity. Its low mechanical properties at fracture are major deficiencies in plain concrete. The low tensile strength is attributed to numerous micro-cracks in plain concrete. The rapid propagation at these cracks under applied stress is responsible for low tensile strength and brittle failure of the material (Aghaee *et al.*, 2015). In structural application, the concrete is provided the reinforcing bars to carry the tensile force once the concrete has cracked, so that it remains largely in compression under load. As mentioned

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

earlier, the tensile failure strain of the reinforced concrete is significantly lower than the yield strain of the steel-reinforced and the concrete crack before any significant load to transfer to the steel. In the industry application, the steel-reinforced needed to carry the tension forces in the concrete. According to the problem of steel-reinforced concrete in the structural application and needed in industry application, a new application of reinforced concrete needs to develop. So, from the previous researches, adding some kind of materials to concrete could improve its mechanical properties and make it lightweight (Kim *et al*., 2010).

1.1. Aim of Study

The main purpose of this study is to fabricate a good lightweight concrete workability with an improved mechanical properties by introducing some different types of recycled steel fibers (staples) in concrete. It will attempted to establish a referential standard range that would give the percentage of recycled materials as well as the percentage of corresponding admixtures for better concrete combinations.

1.2. Objective

Several experimental work procedures and steps were done in this study in order to investigate the effect of various kinds of recycled steel fibers (staples) on properties of concrete and its feasibility in the actual field of construction, especially its compressive strength characteristic.

2. Materials and Methods

2.1. Used Materials

Two types of materials were used in this experimental study that are mainly the normal concrete as a base material and steel staples as additives.

2.1.1. The Main Materials

It is the base material (matrix) which subjected to enhance its compressive strength characteristic. It can be stated as concrete mix designs of Portland cement – Sand – Aggregate – Water.

2.1.2 Additive Materials

They are the waste or recycled steel fibers (staples) used in this study, with a view to reinforcing the normal concrete matrix providing a lightweight concrete mix design with a higher specific compressive strength. These steel fibers are waste materials that are collected from offices and other places at a very minimum cost. They do not have any regular shape and size, and their dimensions vary according to their source of collection. Two kinds of staples scraps steel fibers (with hook end and regular one) fibers of length 10-45 mm and thickness 0.6–0.3 mm respectively were used in this experimental research as shown in Figure (1).

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

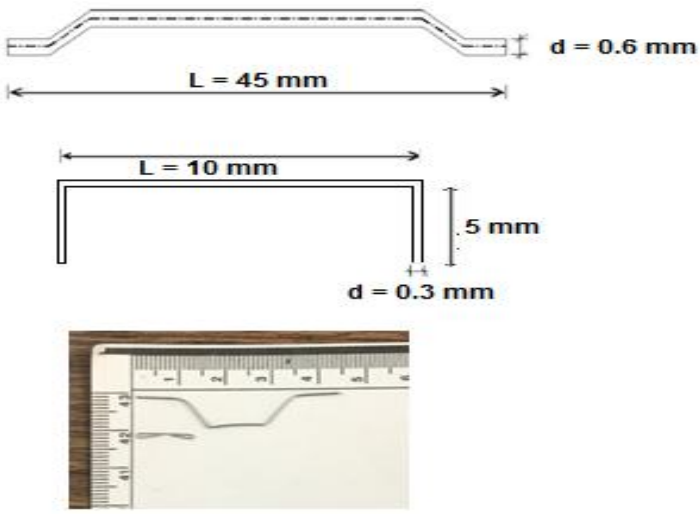

Figure 1. Dimensions of steel fiber used for experimental work.

2.2. The Steel fibers-Concrete Matrix Mixing and Preparing

AIC method was used to mix M25 grade design concrete. So as to examine the concrete compressive strength changes with different fractions of additives, concrete specimens were prepared with various percentages of replacement recycled materials at a constant interval of (0, 0.5, 1, 1.5, and 2%) by weight of cement.

Calculations of the weight of steel fiber for the mix design;

The number of cubes for each constant interval = 6 (0.15×0.15×0.15)= **0.02025 m³**

$$\mathbf{0.5\%} = \frac{0.5}{100} = 0.005 \times 7.56 \times 1000 = \mathbf{38.48\ g}$$

$$\mathbf{1\%} = \frac{1}{100} = 0.01 \times 7.52 \times 1000 = \mathbf{76.95\ g}$$

$$\mathbf{1.5\%} = \frac{1.5}{100} = 0.015 \times 7.48 \times 1000 = \mathbf{115.425\ g}$$

$$\mathbf{2\%} = \frac{2}{100} = 0.02 \times 7.44 \times 1000 = \mathbf{148.8\ g}$$

Table 1. Mix proportions in mass (kg/m³)

SN	SF (%)	W/C Water Ratio	Mix proportion (gm.)				
			Cement	S.F	Sand	Agg.	Water
1	0	0.0085	7.6	0	14.22	25.66	3.20
2	0.50	0.0085	7.56	38.48	14.22	25.66	3.20
3	1	0.0085	7.52	76.95	14.22	25.66	3.20
4	1.5	0.0085	7.48	115.425	14.22	25.66	3.20
5	2	0.0085	7.44	148.8	14.22	25.66	3.20

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

After casting the specimens, after 24 hour rest period was given to the specimens. After 24 hours the specimens were demoded and were subjected to water curing. The specimens were cured in a water tank till test dates.

2.3 Compressive Strength Test

The compressive test was performed on standard cubes of size (150x150x150 mm) after 7, 14, and 28 days of immersion in water for curing. The specimens were tested on digital compression testing machine (ADR 2000 KN Standard) as shown in Figure (2). The compressive strength was calculated by Eqn. (1) as follow:

$$F_{cu} = \frac{P_c}{A} \quad \text{.......... (1)}$$

where:
F_{cu} = compressive strength, (MPa)
P_c = Failure load in compression, (kN)
A = Loaded area of cube, (mm^2)

Figure 2. ADR 2000 kN (standard digital compression testing machine).

3. Results and Discussion

3.1. Compressive Strength

Results of compressive strength are presented in Table (2) and shown in Figure (3) along with three different durations of curing time and at various replacement weight fractions of reinforcement. Also, a graphical presentations of compressive strength is shown in Figures (3-5) for curing days 7, 14, and 28 respectively.

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Table 2. Compressive strength of specimens

Specimens	Compressive Strength (MPa)								
	Normal concrete (N.C)	Regular staples scrap steel fibers (R.S)				Staples scrap steel fibers with hook end (HK.E)			
	Replacement weight with cement percentages (%)								
Curing days	0%	0.5 %	1 %	1.5 %	2 %	0.5 %	1 %	1.5 %	2 %
7	28.02	27.05	28.95	29.14	30.97	26.29	28.70	28.24	29.80
14	31.56	36.06	38.60	38.85	41.29	35.05	38.26	37.65	39.73
28	41.24	30.95	40.76	41.92	42.70	30.84	40.46	46.64	47.80

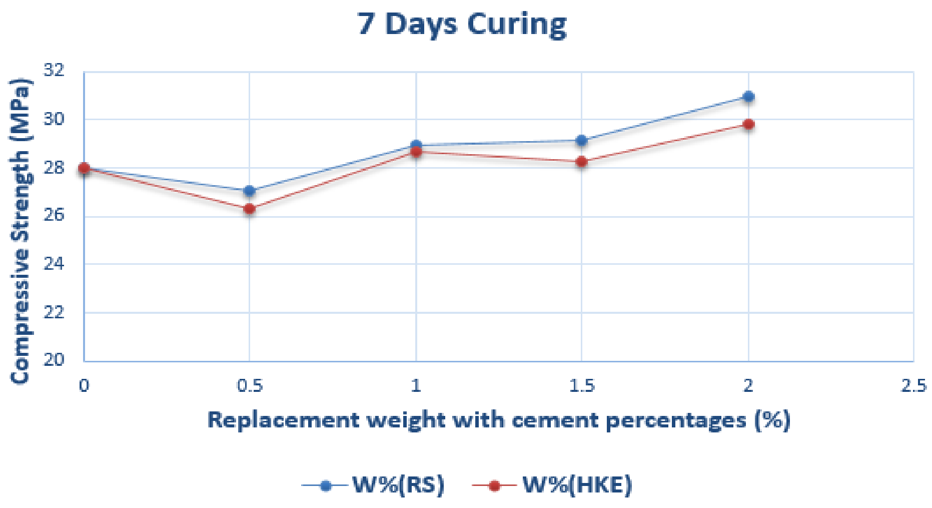

Figure 3. Compressive strength at 7 days curing

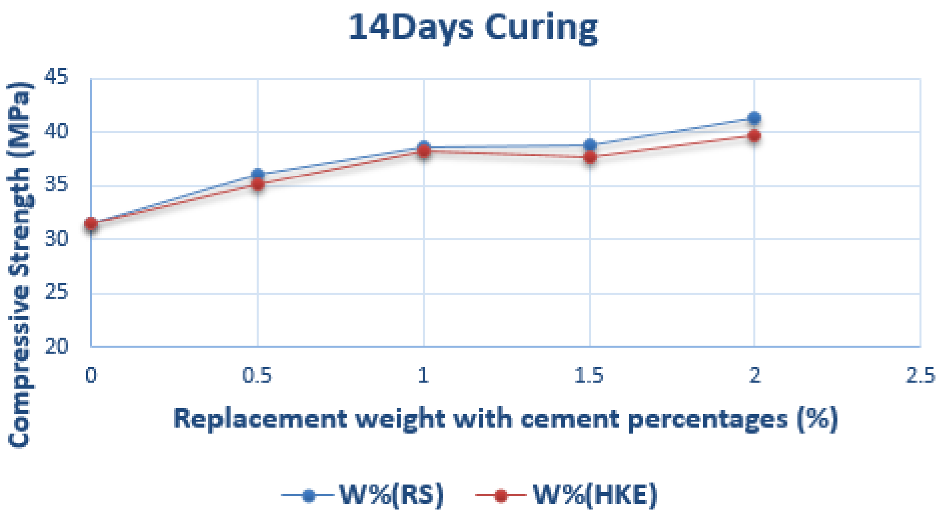

Figure 4. Compressive strength at 14 days curing

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

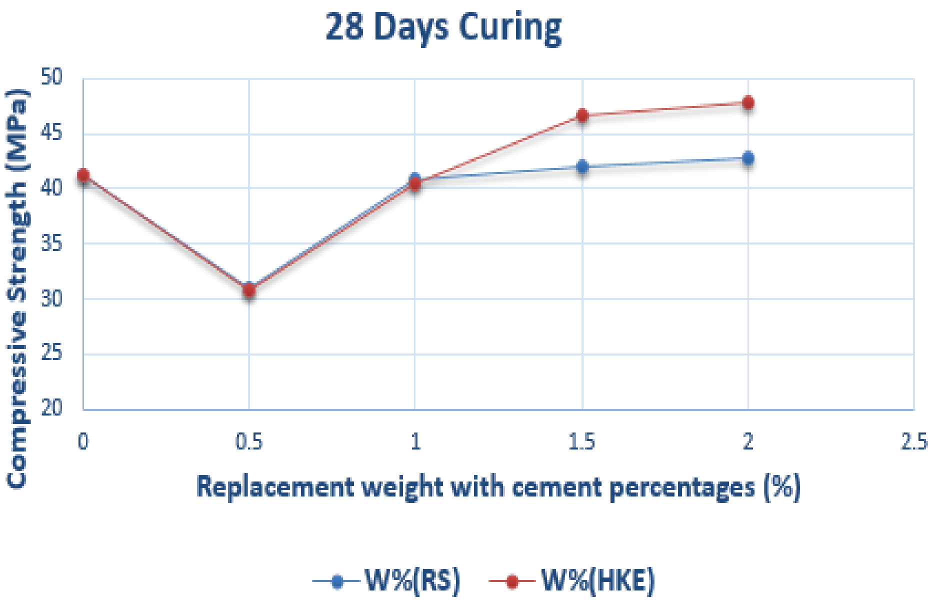

Figure 5. Compressive strength at 28 days curing

The results state that the addition of staples scraps steel fibers to the concrete increases the properties of concrete up to a certain limit. The findings were clearly revealed that 2% and 1.5% hooked end steel fibers content has a noticeable effect on the strength of concrete as compared to normal concrete. It seems that the reason lies behind a gradual slope in the descending part of the stress-strain curves indicates improved ductility and toughness of concrete, and the ratios, shapes, and fiber lengths seem to play an important role in improving the peak strain and the toughness of the concrete. In addition improvements due to fiber addition were relatively more significant at lower matrix compressive strengths.

4. Conclusion and Recommendations

4.1. Conclusion

The conclusion is drawn based on the results; the mechanical properties of concrete are enhanced with the addition of staples scrap steel fibers. The compressive strength of concrete is increased as compared with normal concrete. From the results and discussion, it shows that for 2 % addition of staples hooked end steel fibers, concrete showed overall improvement in compressive strength. A significant improvement in various strengths is observed with the inclusion of hooked end steel fibers in the concrete. However, maximum gain in strength of concrete is found to depend upon the amount of fiber content.

4.2. Recommendations

More elaborative research is required to use steel binding wires as steel fibers. Proper investigation regarding the change in quantity, size should be carried out to know all the relevant properties, and utilization of other such cheap and common waste materials in the concrete to increase its compressive and tensile strengths.

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

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