Effect of Recycle Fiber on the Mechanical Properties of High Strength Concrete

Ahmad Salah[1], Ahmed Tafraoui[1], Bounoua Tab[1]

1Laboratory of Eco-materials: Innovations & Applications (EMIA), Bechar, Algeria.

Correspondent author Email ; salah.ahmed.yahia.ibrahim@univ-bechar.dz

Received: 07/2023, Published: 08/2023

Abstract:

Concrete is experiencing a growing utilization trend in Algeria as a construction material due to its abundant availability and the continuous development of new construction sites. An important aspect for environmental preservation is the incorporation of waste fibers from bicycle brake parts in the production of high-strength concrete. This approach allows for the reuse of materials, thus safeguarding nature from the depletion of these resources. The objective of this research is to investigate the influence of fiber inclusion on the behavior of concrete, specifically focusing on achieving high-strength concrete through the utilization of silica aggregate and steel fibers. Modifications are made to the volume fractions, amount, and length of the fibers used in the concrete mixture. The fibers employed have a diameter of 250 µ and lengths 13 mm, and the volume fractions were 1.5%, 1.6%, 1.65%, and 1.75%. The results obtained demonstrate distinct properties of this new concrete compared to conventional concrete, particularly in terms of deformation and failure characteristics. Additionally, the addition of silica fume contributes to improved flexibility in the concrete. Notably, significant enhancements are observed in mechanical properties such as tensile and flexural strength, as evaluated through three-point bending and compression tests, attributed to the incorporation of steel fibers, with their effectiveness dependent on the quantity and length of the fibers used

Keywords:

High strength concrete, Steel fiber, Mechanical properties, Formulation concrete, Flexural – compressing machine tests.

Tob Regul Sci. ™ 2023;9(1): 3928-3937
DOI: doi.org/10.18001/TRS.9.276

Introduction

High-strength concrete (HSC) possesses distinct engineering characteristics and economic advantages compared to conventional concrete, making it increasingly popular in various construction applications. When used in high-rise buildings, HSC allows for more efficient column spacing and usable floor space, or even enables additional stories without compromising the lower floors (Faisal et al., 1992). In the case of long-span bridges, HSC offers significant cost savings in terms of maintenance while extending the lifespan of the structures (Rabbat et al., 1982). Additionally, HSC exhibits uniform high density and excellent impermeability, providing exceptional resistance to aggressive environments and deterioration. As a result, concrete buildings and structures benefit from enhanced durability (Aïtcin et al., 2019).

While the higher compressive strength of HSC is advantageous, it is worth noting that it tends to reduce the material's ductility, leading to increased brittleness (Koksal, 2003). Compared to normal strength concrete, HSC displays a steeper stress-strain curve during compression, resulting in a more pronouncedly brittle failure mode after reaching the peak load (Toutanji et al., 1999). To address this issue without compromising the compressive strength, a viable strategy is to incorporate discrete steel fibers as reinforcement in HSC (Köksal et al., 2008). As the high-strength steel fiber-reinforced concrete (HSFRC) undergoes hardening, shrinkage, and load-bearing processes that lead to crack formation and propagation, the distributed fibers intersect, block, and even arrest the cracks. Consequently, the addition of fibers contributes to the overall strength of the concrete composite (Atiş et al., 2005).

Several studies have examined the strength enhancement achieved by incorporating steel fibers into HSC. (Khaloo et al., 1996) investigated the effects of steel fiber volume fractions (0.5%, 1.0%, and 1.5%) in HSC, finding improvements in compressive and splitting tensile strengths at the 1.0% fraction, while the modulus of rupture increased up to 1.5%. (Eren et al., 1997) explored the strength-producing influence of steel fibers and silica fume in HSC, indicating that the volume of fibers and their aspect ratio govern the compressive strength of the concrete. The research by (Chunxiang et al., 1999) revealed that the compressive strength of HSFRC increases with maturity, showing a 24% increase in the aged 76-day HSFRC. (Marar et al., 2001) found that the flexural strength of HSFRC improves with an increase in fiber volume for each fiber aspect ratio. Furthermore, (Daniel et al., 2002) reported a 15% advantage in flexural strength for HSFRC compared to its HSC counterpart. These discussions highlight the significant impact of steel fiber additions on compressive strength improvement, while also positively influencing splitting tensile and flexural strengths.

The objective of this paper was to further investigate the strength-enhancing potential of HSFRC containing varying volumes (1.5%, 1.6%, 1.65%, and 1.75%) of recycled steel fibers, as well as analyze the mechanical behavior of HSFRC.

Expermintal Program

2.1 Materials

2.1.1 Cement

The cement used is Portland cement CEMII Gray 52.5 R "cement for high-strength concrete at a young age" of which chemical and chemical characteristics are presented respectively in Table

1, intended for engineering structures and prefabrication. Increased compatibility with various additives (plasticizers, setting retarders, setting and hardening accelerators, etc.). Resists the freeze/thaw cycle better than ordinary cement Thanks to its rapid setting, which is recommended for work in cold weather. Used on heavy and light Prefabrication Infrastructures (foundations) and superstructure elements requiring rapid formwork stripping to optimize completion times Concreting in cold weather all technical work requiring high resistance at a young age and high performance.

TABLE 1.Chemical properties of cement.

Compound%	SiO2	Fe2O3	SO3	MgO	C3S	C3A
cement	25.0 – 31.0	3.5 - 9	2.5 - 3.8	Max 4.0	55.0-75.0	8 ± 3

2.1.2 Aggregates

The sample consists of two types of fine sand, dune sand and crushed quartz (Physical properties shown in table 2 and figure 1). They were collected in the Bechar Province (Taghit) and are naturally occurring sands that pass through a sieve with a mesh size of 0.5 mm, which means their largest diameter is 500 μm, Chemical properties of sand see in table 3.

TABLE 2.Characteristic physic of dune sand.

Characteristic	Result
Apparent volume density(g/cm3)	1.98
Absolute density(g/cm3)	2.68
Sand equivalent%	96.35 (very clean)

TABLE 3.Chemical properties of dune sand.

Compound%	SiO2	Fe2O3	MgO	Na2O	CaO
Sand	98.50	0.06	0.04	0.09	0.03

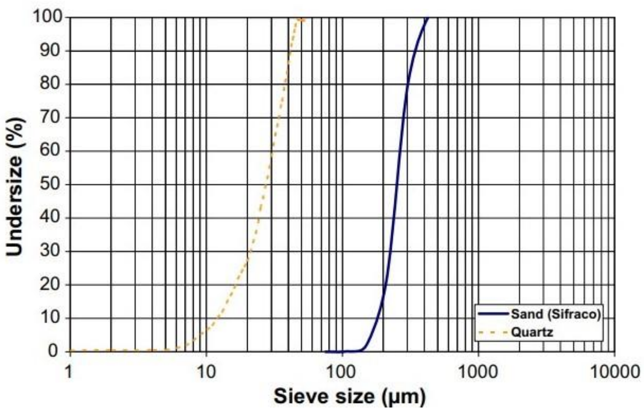

FIGURE 1. Particle size distributions of sand used.(Tafraoui et al., 2009)

2.1.3Addition

The addition silica fume used is ultra-fine a commercially available silica fume marketed out of powder, gray color, chemical properties see in table 4.

TABLE4.Chemical properties of silica fume.

Compound%	SiO2	SO3
Silica fume	>85	<2.5

2.1.4 Superplasticizer

A high water reducer superplasticizer was used, in conformity with standard NF EN 934-2 .

2.1.5 Fiber

Steel fibers, 13 mm length and 250 µm diameter, were employed as seen in figure 2 .

Figure 2 .waste steel fiber length 20 mm.

2.2 Formulation

The comparative study of percentage fiber is carried out by keeping the other parameter of the formulation is constant (w/c, sf/c), see in table 5.

TABLE 5.Formulation of HSC.

composition	HSC1	HSC2	HSC3	HSC4
Cement(kg/m3)	691	691	691	691
Dune sand(kg/m3)	759	759	759	759
Silica fume(kg/m3)	172	172	172	172
Quartz sand(kg/m3)	276	276	276	276
Superplasticizer (kg/m3)	30	30	30	30
Water((kg/m3))	200	200	200	200
Fiber volume (%)	1.75	1.65	1.6	1.5
W/C(%)	0.29	0.29	0.29	0.29
Sp/C(%)	25	25	25	25

2.3 Fabrication

Acoording to (Tafraoui et al., 2009)method, the HSC are mixed and prepared using a mortar mixer with a vertical axis and a capacity of 10 liter . The mixing sequence is as follows:

– mixing at a low speed of the dry powders during 2 min,

– introduction of the water and half of superplasticizer and

mixing at a low speedlasting 3 min,

– introduction of the second part of superplasticizer, and

mixing at a low speeduntil fluxing (duration variable),

– introduction of fibres, and mixing at a high speed during 1 min.

2.4 Test methods

2.4.1 Flexural test

The mechanical tests were conducted on prismatic specimens (4x4x16 cm) following the NFP18-407 standards. They consisted of three-point bending testsas shown in figure 3. The bending device had two supports positioned at a distance of 10 cm from each other. During the test, the stresses were applied at a loading rate of0.05 kN/s until failure occurred. Once the fracture happened, the specimens subjected to bending were transferred to the uniaxial compression device for compression testing, represented by Rfest, is determined using the following formula:

$$\boldsymbol{Rf} = \frac{3PL}{2bh^2} \qquad (1)$$

Where P, L, b, and h respectively denote the force at the moment of specimen rupture, the distance between the supports, and the width and height of the specimen.

FIGURE 3.Flexural strength test three point.

2.4.2 Compressive test

Each half-specimen undergoes compression on its molded lateral faces within a 4x4 cm^2 section, using two hard metal plates with a minimum thickness of 1cm as shown in figure 4. These plates, made of tungsten carbide, have a width of 4 cm. The positioning of the half-specimen between the plates ensures that its intact end extends at least 1 cm beyond the plates, while the longitudinal edges of the specimen remain perpendicular to the plates. Slight tilting of one plate may occur to achieve optimal contact between the plate and the specimen faces. Notably, any deformation of the specimen during the test is not considered.

$$\sigma = \frac{P}{S} \quad (2)$$

P represents the compressive stress at the time of sample failure, and S denotes the cross-section of the sample.

FIGURE 4.Compressive strength test.

Result And Descussion

3.1 Influence of the percentage of waste fiber in compressivestrength

Since the use of high-performance concrete is becoming more prevalent in construction projects, the need to study its performance and reliability is of the utmost importance.

This test entails studying the mechanical behavior of high-strength concrete and proving its ability to withstand compressive, tensile and shear forces. By closely examining these properties, its overall strength and performance in various applications are determined.

Figure 5 illustrates the compressive strength of high-performance concrete, a critical parameter reflecting its load-bearing capacity. Remarkably, the inclusion of 1.75% fibers in the sample(HSC1) yielded the most exceptional performance compared to other samples. These fibers also play a vital role in enhancing the ductility of brittle concrete, allowing it to maintain its cohesion even at the failure stage. This reinforcement contributes to the concrete's ability to endure and adapt, showcasing increased durability and performance.

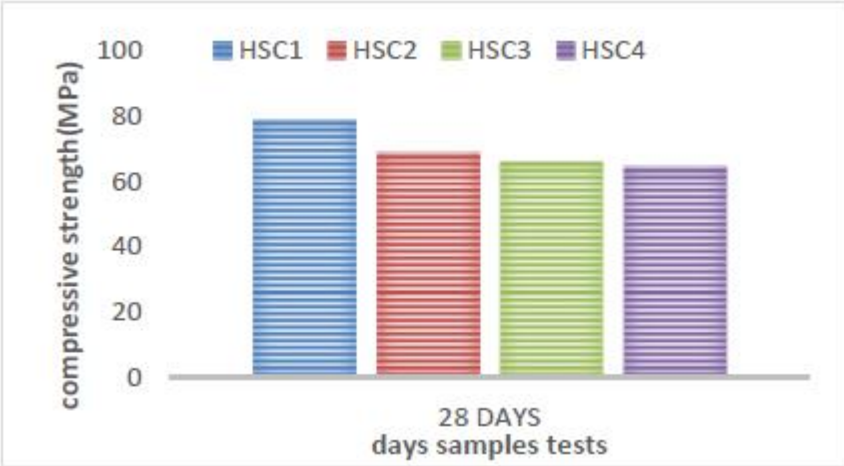

FIGURE 5.Compressive strength of HSC

3.2 Influence of the percentage of waste fiber in flexural strength

High-strength concrete differs in its tensile properties from ordinary concrete.

Figure6shows the role of adding recycled fibers in enhancing the bending strength. The study revealed that HSC1, to which 1.75% of the fibers were added and a length of 13 mm, showed the highest strength among the other ratios. This result sheds light on the role of the appropriate length of the fibers in determining the strength and velocity of bending.as see in figure 3.

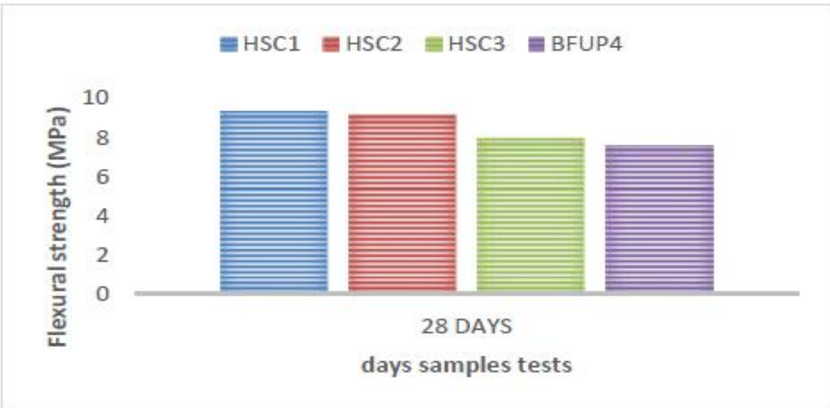

FIGURE 6.Flexural strength of HSC

When the sample is broken into two parts after the bending test, it appears that the fibers are distributed randomly at the borders of the sample, as shown in Figure 7, and the orientation parallel to the sample, giving it the ability to resist internal cracks symmetrically.

FIGURE 7.Orientation and distribution of fibers.

Conclusion

This study resulted in understanding the mechanical behavior of high-strength concrete and its response to the reinforcement of recycled fibers. The results of this research highlight the benefit of using configurations of a certain size and length of fibers to achieve optimal performance in maintaining homogeneity and flexibility.

In addition, the incorporation of recycled fibers achieves the principle of sustainability in terms of reuse, reduces the environmental impact, which makes the concrete environmentally friendly.

Acknowledgment

The authors wish to thank the Directorate General for Scientific Research and Technological Development (D.G.R.S.D.T., Algeria) for financial support of this work. Thanks to the professors and students members of Laboratory of Eco-Materials: Innovations & Applications (EMIA ex. LFGM).

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