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The Effect of Using Sustainable Copper Fiber on Some Mechanical Properties of High Strength Green Concrete

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ABSTRACT

Finding an alternative to materials that pollute during manufacturing, most notably cement, is vital to executing the idea of sustainability in the building sector. It was vital to develop concrete that assists in the reduction of CO_2 (Carbon dioxide) in the atmosphere because industrial wastes contain calcium, silica, and aluminous minerals, such as silica fume, that are employed in the production of high-strength concrete and have parameters that are identical to those of regular concrete. As a substitute for Portland cement, lime cement was utilized, and 15% of the cement's weight was substituted with silica fume. Environmentally friendly fibers (Copper Fiber) created from old electrical and electronic equipment were also employed. The purpose of the study is to produce High Strength Green Fiber Concrete (HSGFC) by incorporating silica fume as a replacement and study the effect of adding fiber on some mechanical attributes. The task needed the creation of a high strength concrete mixture of cement with a compressive strength of 65 MPa in accordance with ACI 211.4R, as well as the development of numerous experimental mixtures that relied on the findings of earlier researchers. The mechanical properties (compressive strength, flexural strength and split tensile strength) of samples are tested at 7, 28 and 60 days with standard curing. The results show that adding sustainable fiber to concrete mix enhances the mechanical properties such as compressive strength by 16% at 28 days, flexural strength by 35% and spilt tensile strength by 44% at 28 days Compared with concrete mix with no fiber. Also, the outcomes showed that it is feasible to develop High Strength Concrete (HSC) using sustainable copper fiber possessing exceptional stress resistance, tensile strength, and flexural strength.

Keywords: Sustainability, Green concrete, Silica Fume (SF), Lime cement, Aspect ratio**.**

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تأثير استخدام الألياف النحاسية المستدامة على بعض الخواص الميكانيكية للخرسانة الخضراء عالية المقاومة

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الخلاصة

يعد العثور على بديل للمواد التي تلوث أثناء التصنيع ، وعلى الأخص السمنت ، أمرًا حيويًا لتنفيذ فكرة الاستدامة في صناعة البناء. كان من الضروري تطوير الخرسانة التي تساعد في تقليل ثاني أكسيد الكربون في الغلاف الجوي لأن مخلفات المصانع توفر مواد سيليكية والومينية وتحتوي على الكالسيوم ، مثل السيليكا فيوم، الذي يستخدم في إنتاج الخرسانة عالية المقاومة بمواصفات مشابهة للخرسانة العادية كبديل للسمنت البورتلاندي ، تم استخدام السمنت الكلسي ، وتم استبدال 15٪ من وزن السمنت بالسيليكا فيوم كما تم استخدام الألياف الصديقة للبيئة (الألياف النحاسية) التي تم إنشاؤها من المعدات الكهربائية والإلكترونية القديمة. الهدف من هذه الدراسة هو إنتاج خرسانة تحتوي ألياف خضراء عالية المقاومة من خلال دمج السليكا فيوم كبديل ودراسة تأثير إضافة الألياف على بعض الخواص الميكانيكية. احتاجت الدراسة إلى إنشاء خلطه خرسانية عالية المقاومة من السمنت بمقاومة انضغاط 65 ميجا باسكال وفقًا لمعهد الخرسانة الامريكي، بالإضافة إلى تطوير العديد من الخلطات التجريبية التي اعتمدت على نتائج الباحثين السابقين. يتم اختبار الخصائص الميكانيكية (مقاومة الانضغاط ومقاومة الانحناء ومقاومة الشد) للعينة في 7 و 28 و 60 يومًا مع المعالجة القياسية. أظهرت النتائج أن إضافة الألياف المستدامة إلى الخرسانة يعزز الخواص الميكانيكية مثل مقاومة الانضغاط بنسبة 16٪ في 28 يومًا ، ومقاومة الانثناء بنسبة 35٪ في 28 يومًا ومقاومة الشد بنسبة 44٪ مقارنة بمزيج الخرسانة بدون ألياف. أشارت النتائج أيضًا إلى أنه من الممكن تطويرخرسانه خضراء عالية المقاومة باستخدام ألياف نحاسية مستدامة مع إجهاد عالي التحمل ومقاومة شد ومقاومة انثناء عالية.

الكلمات المفتاحية: الأستدامة, الخرسانة الخضراء, السيليكا فيوم, السمنت الكلسي, النسبة الباعية .

1. INTRODUCTION

Sustainability is the answer to pollution of all kinds, such as the CO_2 emissions from cement manufacturing, which have negative consequences on the economy, society, and environment **(Hussein and Fawzi, 2021)**. Concrete is commonly utilized as a building material and is a prevalent leader worldwide. It takes 1.6 billion tons of Portland cement, 10 billion tons of rocks, and 1 billion tons of water to generate the 12 billion tons of concrete that is produced annually around the world **(Shah and Wang, 2004)**. Numerous advantages of concrete include its ability to be produced on-site, affordability, high durability, water moisture resistance, and energy efficiency. However, the manufacture of cement, the main adhesive in concrete, necessitates a significant amount of energy and natural resources. Around 1.5 tons of raw materials are required to produce one ton of cement **(Rashad, 2015)**. The need to reduce CO_2 emissions in order to avert a caused by global warming meltdown has made the need to develop an alternative binder very necessary. Interest in alternative compounds that could partially or entirely replace traditional Portland cement has developed due to the demand for more economical and environmentally friendly cement ingredients **(Ahluwalia and Goyal, 2007; Bheel et al., 2018)**. Green concrete is defined as containing at least one recycled component, using environmentally friendly production practices, or being created in a way that is both high-performing and sustainable throughout its entire life cycle **(Suhendro, 2014)**.

The primary challenge facing all upcoming development trends is making concrete more sustainable. Sustainability is defined as "development that satisfies the present without endangering the capacity of future generations to satisfy their requirements" in one definition **(Brundtland and Khalid, 1987)**. Our country's social, economic, and industrial progress have all significantly improved recently. As it does for every country on earth, this will lead to the emergence of new ways of living and an increase in public expectations. Recycling widely dispersed industrial wastes in construction works presents a real possibility of observable cost reductions in civil construction as well as considerable reductions in environmental degradation **(Mymrin et al., 2009)**.

From a global perspective, it has been considered crucial to conserve natural resources, use alternative components in construction materials, and employ energy-efficient building practices attributed to the lack of raw supplies, high cost, and high energy prices, which have a positive impact on the price of construction materials **(Abdullah et al., 2011)**. Therefore, replacing some of the cement with limestone powder has the potential to significantly reduce global carbon dioxide emissions while also safeguarding the environment. Portland cement, crushed clinker, and powdered limestone are combined in cement plants to form limestone cement, a cementitious substance ($CaCO_3$). The use of this type of cement is widespread worldwide. The unique sustainability qualities and economic benefits of these cement materials, which take less energy to produce, are the primary drivers of their research, it generates fewer greenhouse gases than Portland cement (**Mirvalad, 2013)**. Researchers looked into using different cementitious materials in place of cement to create concrete that is more environmentally friendly. The majority of these materials have reactive silica, which when mixed with $Ca(OH)_2$ (one of the cement's hydration products) produces extra gel to enhance several concrete's qualities **(Mehta and Monteiro, 2014; Juenger and Siddique, 2015)**.

A pozzolanic admixture element known as "silica fume" is well-known for improving mechanical characteristics. Compressive strengths between 100 and 150 MPa are easily obtained in the lab using silica fume and superplasticizers. Silica fume reduces permeability, which lowers calcium hydroxide concentration and detrimental ion diffusion, increasing concrete's durability. The capacity of silica fume concrete to stop the corrosion of embedded steel will increase due to its increased durability **(King, 2012)**. Using different fiber types, especially those derived from electronic waste like copper fiber, to reinforce and improve the mechanical properties of concrete **(Kurup and Senthil Kumar, 2017)**.

Portland cement is regarded to be the product that produces the most environmental damage. One ton of Portland cement contributes about one ton of CO_2 gas, a dangerous environmental pollutant that makes up 10% of all CO_2 emissions worldwide. The concrete industry has significant environmental effects. Although reducing the use of concrete is impractical, there are several ways to lessen its negative effects on the environment **(Memon et al., 2021)** leading alternative to cement worldwide. A siliceous or siliceous and aluminous substance is referred to as pozzolan, or any comparable substance, that has little to no cementing value on its own, At normal temperature, calcium hydroxide chemically interacts with calcium hydroxide to create compounds having cementitious characteristics when moisture is present. Industrial waste materials can be used in place of cement as a sustainable solution to these issues. Pozzolanic material has proven to be one of the best cement replacements **(Lepech and Li, 2008)**. **(Mirza et al., 1991)** demonstrate how OPC was utilized in mortar and concrete combinations with powdered tuff, powdered slag, and silica fume. The test results revealed that although the paste, mortar, and concrete specimens containing cement blends have higher long-term strengths than OPC specimens, their short-term strengths are lower. When fly ash (8-12-16%) is substituted with cement, the compressive strength of Reactive powder concrete rises, and at ages 7, 28, and 90 days, the optimal Fly ash percentage that produced the greatest resistance to reference samples was 8% **(Muhsin and Fawzi, 2021)**.

(**Amouri and Fawzi, 2022)** discover that geopolymer mortar made from FA and slag is favored over conventional concrete because of its improved characteristics and low environmental impact, A pozzolanic admixture element known as "silica fume" is well-known for improving mechanical characteristics. Compressive strengths between 100 and 150 MPa are easily obtained in the lab using silica fume and superplasticizers. The results of the impact test indicate an increase of 40% in terms of additional micro steel fiber for the first crack results and a failure rate of 72% for the specimen, the study's findings **(Fawzi, 2022).** Using different fiber types, especially those derived from electronic waste like copper fiber, to reinforce and improve the mechanical properties of concrete **(Kurup and Senthil Kumar, 2017)**.

In comparison to traditional concrete, the rates at which concrete's compressive, tensile, and flexural strengths increased with copper fiber were 23.76%,46.4 %, and 38.8% as a result of the study **(Sofi and Gopu, 2019)**. The preliminary compressive strength of commonly used concrete created with copper fibers of 0.5% is higher than that of traditional concrete made without fibers **(Hussein and Fawzi, 2021a)**.

This work aims to study the effect of using sustainable fiber (copper fiber) on the properties of green concrete.

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Cement

The Portland Lime Stone Cement (IL) utilized in this study is composed of finely ground Portland Cement Clinker and a little amount of Gypsum (calcium sulfate dehydrate). According to **Table 1** below, these chemical and physical characteristics conform to factory Specifications (3868/2011).

2.1.2 Fine Aggregate (Sand)

In this project, the concrete mixtures included sand from the Al-Ekhadir quarry. The physical and chemical characteristics of fine aggregate are shown in **Tables 2 and 3**. The test's findings that the sand's grade is in Zone 2 and meets Iraqi standards (**IQS No. 45, 1984)**.

Table 1. Test Results and Specifications Limits of Limestone Portland Cement (42.5 R)

Test Type	Properties		Test results	Specification Limits Limestone cement
Physical tests	Setting time	Initial (mins)	115	Min. 45
		Final (hrs.)	4.71	Not limited
	Compressive strength (MPa) at age:	2 days	20.78	Min. 20
		28 days	43.55	Min. 42.5
Chemical tests	SiO_2 (%)		19.07	Not limited
	Al_2O_3 (%)		4.09	Not limited
	Fe_2O_3 (%)		4.23	Not limited
	CaO (%)		60.05	Not limited
	L.S.F (%)		0.97	Not limited
	MgO (%)		3.26	5 Max.
	SO_3 (%) Max	C_3A <5%	2.22	2.5
		C_3A >5%	Not applicable	2.8
	Loss on Ignition (%)		9.16	Not limited
	Insoluble residue (%)		0.91	Not limited
	C_3S (%)		59.45	Not limited
	C_2S (%)		9.61	Not limited
	C_3A (%)		3.65	Not limited
	C_4AF (%)		12.88	Not limited

Table 2. Grading of fine aggregate.

Sieve size (mm)	Passing % of sand	Limits of **(IQS No.45, 1984)** Zone 2
10	100	100
4.75	100	90-100
2.36	88.6	75-100
1.18	66.8	55-90
0.6	49.8	35-59
0.3	18.6	8-30
0.15	3.36	0-10

Table 3. Physical and chemical properties of fine aggregate.

Properties of sand	Test result of sand	Limits of **(IQS No. 45, 1984)**
Fineness modulus	2.71	-
Specific gravity	2.64	-
Absorption	0.7%	-
SO_3	0.24 %	≤ 0.5%
Dry rodded density	1604 kg/m^3	-

2.1.3 Coarse Aggregate (gravel)

Natural gravel with a nominal aggregate size of (5-14 mm) was used as the coarse aggregate for all mixtures. It was from the area of Al-Nibaee. According to **Tables 4 and 5,** the aggregate satisfies the physical and chemical requirements of Iraq **(IQS No. 45, 1984).**

Table 4. Grading of coarse aggregate

Sieve size (mm)	Passing % of gravel	Limits of **(IQS No. 45, 1984)** (5-14) mm
20	100	100
14	100	90-100
10	64.7	50-85
5	2.6	0-10

Table 5. Aggregate's physical and chemical characteristics.

Properties of gravel	Test result of gravel	Limits of **(IQS No. 45, 1984)**
Specific gravity	2.653	-
Absorption	0.8%	-
SO_3	0.06%	≤ 0.1%
Dry rodded density	1641 kg/m^3	-

2.1.4 Mixing Water

Drinkable water was utilized for both blend and cure. Confirmed by the Iraqi standards **(IQS 1703, 1992)**

2.1.5 Silica Fume

Silica Fume (SF), obtained from (Sika Company Iraq), and complies with **(ASTM C1240, 2015)** has an activity index of 120 percent. **Tables 6 and 7**. Contains technical information on silica fume.

Table 6. Physical tests of silica Fume (SF)

Physical properties	Test results	**(ASTM C1240, 2015)** Specification
Percent Retained on 45-µm (No. 325) sieve	7	≤10
with Portland cement at 7 days, accelerated Pozzolanic strength Activity Index	120	≥105
Specific surface m^2/g	17	≥15

Table 7. Chemical analysis of silica Fume (SF)

Oxide Composition	Test results*	**(ASTM C1240, 2015)** Specification
SiO_2	92.84	≥85.0
Moisture Content%	0.33	≤3.0
Loss on Ignition	1.57	≤6.0

* Given by the manufacturer

2.1.6 Superplasticizer

Superior-quality concrete additive for superplasticizer. (Sika Viscocrete -5930L), a third-generation superplasticizer that met the prerequisites of **(ASTM C494/ C494, 2015)** type G and F To achieve perfect cohesion, better flowability, and a significant reduction in water content. By increasing the permeability of the cement paste as the w/c ratio falls, a superplasticizer can be used to improve certain qualities of concrete and prevent flaws like honeycombing. In this work, cement was mixed with a superplasticizer in a weight-proportional amount.

Table 8. Technical description of superplasticizer (given by manufacturer)

Properties	Technical description
Basis	An aqueous solution of modified polycarboxylate
Boiling	100°C
Hazardous Decomposition Products (Hazardous Reactions)	No known hazardous reactions.
Odor	None
Density	1.2 kg/L
Labeling	No hazard label is necessary.
Chloride content	None
Poisoning	Non-toxic with acceptable safety regulations and health
Dosage	(0.2- 0.8) %by weight of cement
Appearance	Turbid liquid

2.1.7 Copper Wire Fiber

There are many uses for copper wire in electrical and electronic device manufacturing. For instance, computer peripherals as a whole, electrical machine windings, and other appliances like refrigerators. Since it is a sustainable fiber The used fiber in this work had an aspect ratio of (120) and measurements of (30+-2) mm in length and (0.25) mm in diameter.

3. SELECTION OF MIX PROPORTIONS FOR THE REFERENCE CONCRETE

There were many test mixes made With a required minimum compressive strength of 65 MPa after 28 days with high-range water reduction admixture (HRWRA), the **(ACI 211 4R, 2008)** and as well as the existing literature on high-strength concrete mix design employed, such as **(Annadurai and Ravichandran, 2014)**. To attain an equal design strength of 65 MPa at age 28 days, these experimental combinations must either change the amount of cement and the % replacement of silica fume or the amount of superplasticizer. The highest strength is achieved in this investigation when silica fume is 15% of the cement's weight. The weight-to-volume ratio of the cement, sand, and gravel mixture is 1:1.5:2.4; the cementitious content is 450 kg/m3; the w/cm ratio is 0.31; and the slump value is (50-100) mm. 3.5 liters per 100 kg of cement is the ideal HRWRA dose for the reference mix. The mix's (1%) copper fiber content was added. In **Table 9** and SF (15%), the volume of concrete for high-strength concrete is indicated along with the cement weight and superplasticizer.

Table 9. Details of mix design for concrete mixes.

Mix Symbol	Sp. L/100 kg	w/cm	Cement kg/m³	Sand kg/m³	Gravel kg/m³	Silica Fume kg/m³	Fiber Length mm	Fiber Dim. mm	Fiber Aspect ratio
MR (Reference Mix)	0.8%	0.31	382.5	700	1100	67.5	0	0	0
MF1 (1%fiber)			382.5	700	1100	67.5	30	0.25	120

4. PREPARATION OF CONCRETE SPECIMENS

The internal surfaces of the steel molds were cleaned and lubricated with oil to prevent concrete adhesion once it had hardened. The molds were loaded with layers of concrete, and after each layer was added, it was compressed using a table vibrating in accordance with **(ASTM C192/C192M, 2016)** for long enough to let any trapped air out. Specimens were compacted and leveled by hand troweling; then a nylon sheet was placed on top to keep the humidity level constant for 24 hours. The samples were removed from the molds. And cure before the exam was conducted. The samples were removed from the molds and allowed to cure before the test starts. Cubical specimens of (100×100×100mm) are used for each concrete mix to assess its compressive strength. Prism of (100x100x400mm) is used for flexural strength and a cylinder (150 x 300 mm) was employed for the splitting tensile strength test

5. CURING

After casting, the specimens are kept dry and covered with plastic sheeting for 24 hours to avoid water evaporation before being submerged in a tank of water that is 23°C and above. Ages (28, 60, and 60) days were tested in accordance with **(ASTM C192/C192M, 2016)**.

6. TESTING OF HARDENED CONCRETE

6.1 Compressive Strength Test

Using (100x100x100 mm) cubes, the compressive strengths of the concrete mixtures were assessed based on the British Standard **(BS EN 12390-3, 2019).** Each concrete cube was cleaned on all sides before being placed in the compression device, making sure that the compressive load was applied steadily and perpendicularly to the direction of pouring concrete into the molds. This test was conducted in the Construction Materials lab at the University of Baghdad. By dividing the failure load by the load's applied area for each cube, the compressive strength was computed. When the cubes were assessed at ages 7, 28, and 60 days, three cubes on average were taken for each mix.

6.2 Flexural Strength Test

In line with **(ASTM C293, 2002)**, Flexural strength was assessed in the labs of the Civil Engineering Department using the center point method. At 7, 28, and 60 days, prisms were examined, and an average of three prisms were collected for each combination. In this experiment, the prism specimens (100x100x400) mm were simply supported with a 300 mm spread. The modulus of rupture was determined by applying the formula.

$$Fr = \frac{3PL}{2bd^2} \quad (1)$$

where:
F_r is the flexural strength (MPa).
P is the maximum applied load indicated by the tested machine (N).
L is the average length of the specimen (mm).
b is the average width of the specimen (mm).
d is the average depth of the specimen (mm).

6.3 Splitting Tensile Strength Test

The tensile splitting strength of cylindrical concrete specimens of (150 mm x 300 mm) was measured in this test using the compressive machine at the Civil Engineering Department labs in accordance with **(ASTM C 496, 2004)**. A concrete cylinder specimen would undergo this test procedure's diametric compression along its side until tensile failure occurred. The compressive machine's steel plate is utilized to evenly disperse the applied load. Along the length of the cylinder. The three-cylinder average was determined using the equations below after the cylinders were assessed at ages 7, 28, and 60 days.

$$\tau = \frac{2P}{\pi LD} \quad (2)$$

where: τ is the splitting tensile strength (MPa).

P is the Max. applied load (N).
L is the length (mm).
D is the diameter (mm).

7. RESULTS AND DISCUSSION

7.1 Compressive Strength

Among the most crucial characteristics of hardened concrete is compressive strength, which is closely related to other physical features. The results of cubes of compressive strength tests at 7, 28, and 60 days of (100x100x100 mm) for all mixing concrete are shown in **Table 10 and Fig. 1.** For concrete at 7, 28, and 60 days. High-strength concrete (HSC). Must now be produced with silica fume (15%) due to significant developments made in the cement paste-aggregate interfacial zone. The extremely minute particles that make silica fume increase the adherence of the cement paste to the aggregate by raising the interfacial zone's density **(Atcin and Mindess, 2011)** came with a similar result. Owing to its pozzolanic activity, concrete's mechanical strengths can be significantly increased. The filling action of silica fume outweighs its pozzolanic effect. The most well-known effect of silica fume on concrete is the strengthening of the cement paste-aggregate interface, which is generally accepted as the concrete matrix's weakest point. The same findings were reached by (**Atiş et al., 2005)**. The copper fiber-reinforced high-strength concrete sample demonstrated noticeably better strength than the reference (MR) specimens. This may be attributed due to copper fiber's role in developing compressive strength, which serves as a bridge to prevent or delay the development of cracks to a specific proportion of fiber (1%) since more fiber addendum would cause non-homogeneous mix and create weak spots that lower compressive strength. The same findings were achieved by **(Suhirkam et al., 2020)**.

Table 10. Results of Compressive Strength test.

Mix Symbol	Compressive strength (MPa)			Fiber Aspect ratio
	7 Days	28 Days	60 Days	
MR (Reference mix)	44.8	65.2	67	0
MF1 (1%fiber)	55	75.6	78.5	120

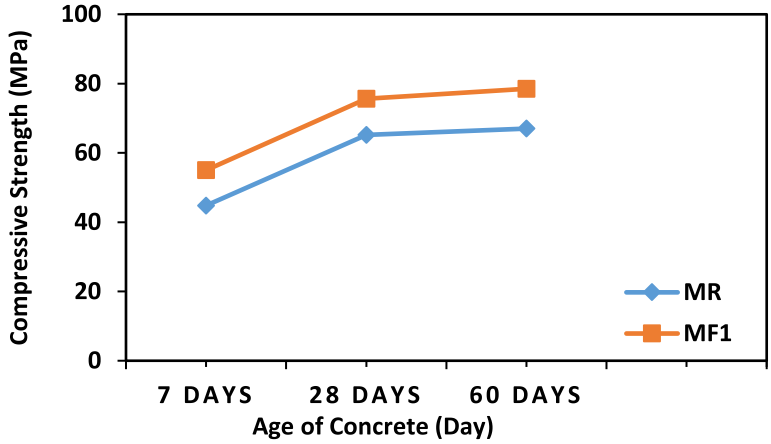

Figure 1. Compressive strength test results.

7.2 Flexural Strength

The flexural strength test procedure gauges how materials respond to straightforward beam loading. Prisms measuring (100x100x400) mm were used for the test. Tried at various ages (7, 28, 60 Days). The outcomes of the flexural strength tests for concrete mixes are shown in **Table 11.** and **Fig.2.** Copper fibers and silica fume were added to the concretes, which greatly improved their flexural strengths. Concretes made with copper fiber plus silica fume performed better than those made with only silica fume. It was discovered that copper fiber and silica fume seemed to have a more notable flexural strength affected, silica fume was found to significantly increase flexural strength. Consistent with the outcomes of **(Bhanja and Sengupta, 2005)**. Flexural strength has improved as a result of the fibers' capacity to contain and span fissures.

Table 11. Results of Flexural Strength

Mixes	Flexural Strength (MPa) Age (Days)			Fiber Aspect ratio
	7	28	60	
MR (Reference Mix)	7.2	9.67	10.4	0
MF1 (1%fiber)	9.6	13.1	14.2	120

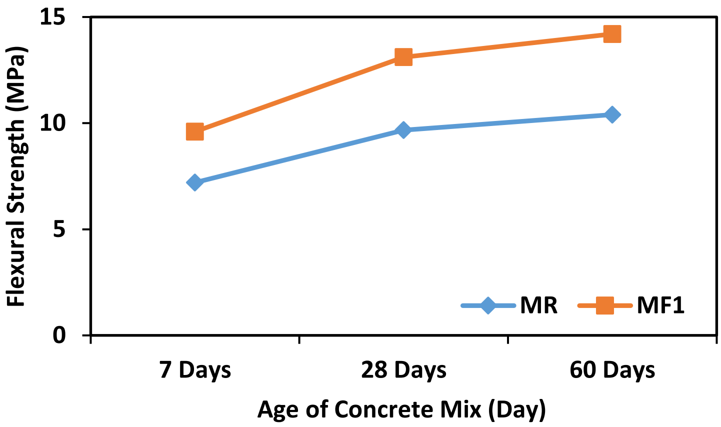

Figure 2. Flexural Strength test result

7.3 Splitting Tensile Strength

Test results for splitting tensile strength of concrete mixtures are presented in **Table 12** and **Fig. 3**. The concretes' tensile splitting strengths were significantly increased by including copper fibers and silica fume. Concretes made with silica fume and copper fiber performed better than those made with only silica fume. The fibers play a crucial role in this increase in splitting tensile strength because they prevent microscopic cracks in concrete composite from growing into macroscopic cracks and because they can withstand tension being transferred from one end to the other before separating, pulling out, or breaking from the matrix.

Table 12. Outcomes of the Splitting Tensile Strength Test

Mixes	Splitting Tensile Strength (MPa) Age (Days)			Fiber Aspect ratio
	7	28	60	
MR (Reference Mix)	4.85	6.82	7.1	0
MF1 (1%fiber)	6.88	9.83	10.0	120

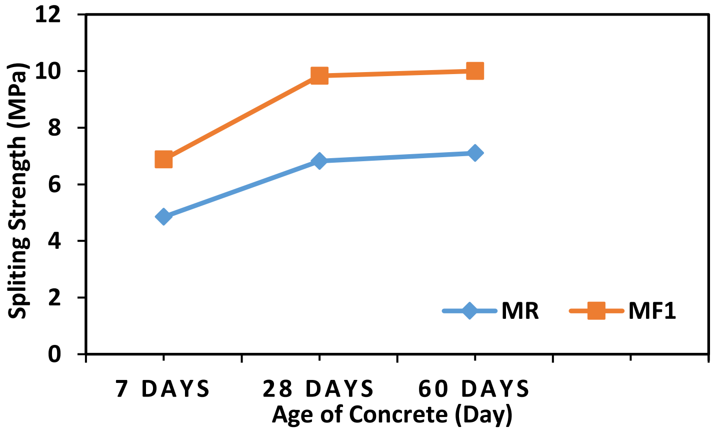

Figure 3. Splitting Tensile Strength test results

8. CONCLUSIONS

The most significant discoveries of the current study are based on the experimental results, and they are as follows:

- One of the finest alternatives to conventional concrete is high-strength green concrete, which is made of limestone cement, silica fume as a replacement, and copper fiber as a sustainable fiber in addition to other aspects that make it superior to conventional concrete.
- Green concrete with high strength has been made using sustainable copper fiber. The rise in compressive strength for 7, 28, and 60 days is 23%, 16%, and 17% higher than high-strength concrete without fiber.
- For all ages of 7, 8, and 60 days, the flexural strength of concrete with sustainable copper fibers is higher (33%, 35%, and 36%) than that of high-strength concrete without fibers.
- Split tensile strength for high-strength green concrete using sustainable copper fibers (MF1) increases by 41%, 44%, and 41.6% for 7, 28, and 60 days, in comparison to the reference mix, without fiber (MR).

NOMENCLATURE

Symbol	Description	Symbol	Description
b	The average width of the specimen (mm).	τ	The splitting tensile strength (mpa)
d	The average depth of the specimen (mm).	HSC	High Strength Concrete
F_r	The flexural strength (MPa).	SF	Silica fume
L	The average length of the specimen (mm).	L	The length (mm).
P	The maximum applied load indicated by the tested machine (N).	HSGFC	High strength green fiber concrete
P	The Max. Applied load (N)	D	The diameter (mm).

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Credit Authorship Contribution Statement

Ahmed Najm Abdullah: Writing – original draft, Validation, Methodology.
Nada Mahdi Fawzi: Review & editing, Validation, Proof reading.

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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