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The Effect of Using Different Aspect Ratios of Sustainable Copper Fiber on Some Mechanical Properties of High-Strength Green Concrete

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ABSTRACT

To achieve sustainability, use waste materials to make concrete to use alternative components and reduce the production of Portland cement. Lime cement was used instead of Portland cement, and 15% of the cement's weight was replaced with silica fume. Also used were eco-friendly fibers (copper fiber) made from recycled electrical. This work examines the impact of utilizing sustainable copper fiber with different aspect ratios (l/d) on some mechanical properties of high-strength green concrete. A high-strength cement mixture with a compressive strength of 65 MPa in line with ACI 211.4R was required to complete the assignment. Copper fibers of 1% by volume of concrete were employed in mixes with four different aspect ratios (20, 40, 60, and 120). At 7, 28, and 60 days after typical curing, the samples' mechanical characteristics (compressive strength, flexural strength, and split tensile strength) are assessed. A reported increase in compressive strength of (2, 1.6, and 1.4) in (7, 28, and 60 days) for concrete with a high aspect ratio 120, compared to concrete with a low aspect ratio 20. The flexural strength of high-strength green concrete with fibers of a higher aspect ratio 120 was (23, 11, and 12.6%) times higher for all ages compared to low aspect ratio 20. The split tensile strength rose (1.7, 1.5, and 1.6%) for (7, 28, and 60 days), respectively, for concrete with a high aspect ratio 120, compared to concrete with a low aspect ratio 20. It was found that using fibers with a large aspect ratio improved the mechanical properties of concrete more than fibers with a small aspect ratio.

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

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تأثير اختلاف النسبة الباعيه للالياف النحاسية المستدامة على بعض الخواص الميكانيكية للخرسانة الخضراء عالية المقاومة

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الخلاصة

لتحقيق الاستدامة اقترح استخدام النفايات في صناعة الخرسانة من أجل استخدام مكونات بديلة وتقليل إنتاج السمنت البورتلاندي. في هذه الدراسة تم استخدام السمنت الكلسي بدلاً من السمنت البورتلاندي ، تم استبدال 15٪ من وزن السمنت بالسيلكا فيوم. كما تم استخدام ألياف صديقة للبيئة (ألياف نحاسية) مصنوعة من أجهزة كهربائية . يهدف هذا البحث إلى دراسة تأثير استخدام ألياف نحاسية مستدامة بنسب باعية مختلفة (20، 40، 60، و 120) على بعض الخواص الميكانيكية للخرسانة الخضراء عالية المقاومة. من أجل إكمال المهمة ، كان مطلوب خلطه خرسانية عالية المقاومة بمقاومة انضغاط 65 ميجا باسكال بما يتماشى مع توصيات معهد الخرسانة الامريكي ، بالإضافة إلى تحضيرخلطات تجريبية مختلفة استندت الى نتائج الباحثين السابقين. تم استخدام كمية الألياف النحاسية (1٪) من حيث حجم الخرسانة في الخلطات بأربع نسب باعية مختلفة (20 ، 40 ، 60 ، 120). في عمر 7 و 28 و 60 يومًا بعد المعالجة النموذجية ، تم تقييم الخصائص الميكانيكية للعينات (مقاومة الانضغاط ومقاومة الانثناء ومقاومة شد الانقسام). أظهرت النتيجة أن الزيادات في مقاومة الانضغاط كانت 2٪ و 1.6٪ و 1.4٪ في 7 و 28 و 60 يومًا للخرسانة ذات نسبة باعية (120) ، مقارنةً بالخرسانة ذات نسبة باعية (20). كانت مقاومة الخرسانة الخضراء للانثناء مع الألياف ذات نسبة باعية(120) أعلى (23٪ ، 11٪ ، و 12.6٪) مرة لجميع الفئات العمرية مقارنه بالخلطات الخرسانيه ذات نسبه باعية(20).ومقاومة الشد الانقسام ترتفع 1.7٪ ، 1.5٪ ، و 1.6٪ لمدة 7 و 28 و 60 يومًا على التوالي للخرسانة ذات نسبة باعية (120) ، مقارنة بالخرسانة ذات النسبة المنخفضة20 . مماسبق عرضه من النتائج ان استخدام الالياف ذات النسبه الباعيه الكبيره ادت الى تحسين الخصائص الميكانيكية للخرسانه بشكل اكبر من الالياف ذات النسبه الباعيه الصغيره.

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

1. INTRODUCTION

Sustainability is the solution to pollution of all kinds, including the CO_2 emissions from cement manufacture that harm the economy, society, and environment **(Hussein and Fawzi, 2021)**. One of the building materials that is utilized the most commonly worldwide is concrete. The 12 billion tons of concrete produced annually around the globe require 1.6 billion tons of Portland cement, 10 billion tons of rocks, and 1 billion tons of water **(Shah and Wang, 2004)**. The product that is thought to cause the most environmental harm is Portland cement. A hazardous environmental pollutant that accounts for 10% of all CO_2 emissions worldwide, an estimated one ton of CO_2 gas is produced by one ton of Portland cement. The concrete industry undoubtedly has significant adverse effects on the environment. Although it is difficult to stop using concrete completely, there are a variety of strategies to decrease its harmful effects on the environment **(Memon et al., 2021)**. Creating an alternative binder has become critically important due to the requirement to minimize CO_2 emissions to prevent a disaster brought on by global warming. Because of the demand for more affordable and ecologically friendly cement ingredients, interest in alternative substances that could partially or completely replace conventional Portland cement has grown **(Ahluwalia and Goyal, 2007; Bheel et al., 2018)**. When natural resources become more and more costly, people are looking for substitutes, like recyclable materials.

Ash from rice husks, ash from sawdust, ash from tile, silica fume, fly ash, coal bottom ash, and dust from limestone are a few examples of materials. Limestone, a key component in cement creation, is the most common source of calcium carbonate. The primary elements that make up limestone are calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and sulfate. The key ingredients are calcium and magnesium carbonate **(Harris and Holmstrom, 1982)**. Green concrete is made in a high-performing and sustainable way for its entire life cycle, using environmentally friendly production methods or including at least one recycled component **(Suhendro, 2014)**. The absence of natural resources, their high cost, and the high cost of energy, which has led to an increase in the price of construction materials, it has been determined from a global perspective that it is essential to conserve natural resources, use alternative components in construction materials, and use energy-efficient building practices **(Abdullah et al., 2011)**. Hence, using limestone powder in place of some cement might dramatically lower global carbon dioxide emissions while simultaneously protecting the environment. Limestone cement, a cementitious material, is created at cement factories by combining Portland cement, crushed clinker, and powdered limestone ($CaCO_3$). The use of this type of cement is widespread around the world. These cement materials' unique sustainability characteristics and practical advantages, which require less energy, are the main driving forces behind their development. Fewer greenhouse emissions are produced than with Portland cement **(Mirvalad, 2013)**. To produce concrete with a better environmental impact, researchers investigated using various cementitious materials instead of cement.

Most of these ingredients contain reactive silica, which, when combined with $Ca(OH)_2$, one of the cement's hydration products, creates extra gel to improve a number of the properties of concrete **(Mehta and Monteiro, 2014; Juenger and Siddique, 2015)**. Silica fume, a pozzolanic admixture element, is widely recognized for enhancing mechanical properties. It is simple to produce compressive strengths between 100 and 150 MPa in the lab by employing silica fume and superplasticizers. The strength of concrete is increased by silica fume because it lowers permeability, reducing calcium hydroxide concentration and harmful ion diffusion **(King, 2012)**. In terms of strength and hardness, conventional concrete has many benefits but has some drawbacks, such as weak tensile strength and short durability. Yet, one effective solution to this issue can be the usage of fiber in concrete applications. The main benefit of fiber materials is their great flexibility, which enables them to accommodate the imperfections in concrete that are inherently present. Concrete's mechanical and physical characteristics can be greatly enhanced in a given percentage by incorporating fiber material. Concrete's compressive strength and crack resistance have also been enhanced to meet the demands for strength and hardness. Unlike other building materials, fiber materials' mechanical qualities can effectively boost concrete toughness **(Tong, 2020)**. They

enhanced and strengthened the mechanical qualities of concrete using various fiber types, particularly those made from electronic waste, such as copper fiber **(Kurup et al., 2017)**.
High Strength Concrete (HSC) improved compressive strength is the most important of its functional properties. With the use of additives like silica fume for the production of concrete with compressive strengths of more than 50 MPa is possible that silica fume, in particular, can speed up the process. Silica fume concrete produces a thick concrete matrix aided by fine silica fume particles equally distributed among bigger cement particles. This results in a noticeable improvement in concrete strength. Superplasticizers and effective vibration compaction are used to perform the densification process, which boosts strength **(De Larrard and Malier, 2018)**. OPC is used in mortar and concrete mixtures with silica fume, powdered slag, and powdered tuff. The test results showed that despite having stronger long-term strengths than OPC specimens, paste, mortar, and test specimens containing cement blends have weaker short-term strengths. When fly ash (8-12-16%) is used in place of cement, reactive powder concrete's compressive strength increases. At ages 7, 28, and 90 days, the best fly ash percentage for producing the greatest resistance to reference samples was 8% **(Muhsin and Fawzi, 2021)**.
The findings of **(Amouri and Fawzi, 2022)** indicate that FA and slag-based geopolymer mortar is preferred to conventional concrete because of its eco-friendly components and improved qualities. Silica fume, a pozzolanic admixture element, is widely recognized for enhancing mechanical properties. It is simple to achieve laboratory compressive strengths between 100 and 150 MPa by utilizing silica fume and superplasticizers**. (King, 2012)**. The impact test findings show a failure rate of 72% for the specimen and an increase of 40% in additional micro steel fiber for the first crack results, findings from the study **(Fawzi and Amouri, 2022)**. The research discovered that concrete's compressive strength, tensile strength, and flexural strength with copper fiber increased by 23.76%, 46.4%, and 38.8% compared to conventional concrete **(Sofi and Gopu, 2019)**. Traditional concrete built with 0.5% copper fibers has an insufficient compressive strength higher than conventional concrete made without fibers, a consequence of research **(Hussein and Fawzi, 2021a)**.
This study aims to produce green, environmentally friendly, high-strength concrete using Lime cement instead of Portland cement, and 15% of the cement's weight was replaced with silica fume. Also used were eco-friendly fibers (copper fiber) to study the effect of using sustainable fibers with different aspect ratios on the mechanical properties of this environmentally friendly concrete.

2. MATERIALS AND METHOD

2.1 Materials

2.1.1 Cement

Portland Cement Clinker that has been finely ground and a small amount of gypsum (calcium sulfate dehydrate) make up the Portland Lime Stone Cement (IL) used in this study. These chemical and physical qualities meet laboratory requirements, as shown in **Table 1**, confirmed to factory Specification (3868/2011).

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

Test Type	Sample Lab. No.		CPCh384	Specification Limits
	Cement trademark and field No.		Ce2211082544	Limestone cement
	Property		Test results	
Physical tests	Setting time	Initial (mins)	117	Min. 45
		Final (hrs.)	4.72	Not limited
	Compressive strength (MPa) at age:	2 days	20.77	Min. 20
		28 days	43.53	Min. 42.5
Chemical tests	SiO_2 (%)		19.06	Not limited
	Al_2O_3 (%)		4.06	Not limited
	Fe_2O_3 (%)		4.25	Not limited
	CaO (%)		60.03	Not limited
	L.S.F (%)		0.95	Not limited
	MgO (%)		3.24	5 Max.
	SO3 (%) Max	5% <C3A	2.24	2.5
		5% >C3A	Not applicable	2.8
	Loss on Ignition (%)		9.18	Not limited
	The insoluble residue (%)		0.92	Not limited
	C_3S (%)		59.47	Not limited
	C_2S (%)		9.62	Not limited
	C_3A (%)		3.67	Not limited
	C_4AF (%)		12.87	Not limited

2.1.2 Fine Aggregate (Sand)

Sand from the Al-Ekhadir quarry was incorporated into the concrete mixtures for this project. **Tables 2** and **3** display the fine aggregate's physical and chemical parameters. According to the test outcomes, the sand is of Zone 2 quality and complies with Iraqi requirements (**IQS No. 45/1984).**

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	88.9	75-100
1.18	66.8	55-90
0.6	502.	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	The test result of the sand	Limits of IQS No. 45/1984
Fineness modulus	2.72	-
Specific gravity	2.65	-
Absorption	0.6%	-
SO_3	0.22 %	≤ 0.5%
Dry rodded density	1604 kg/m^3	-

2.1.3 Coarse Aggregate (gravel)

The coarse aggregate for all combinations was natural gravel with a nominal aggregate size of (5–14 mm). It was from the Al-Nibaee region. The aggregate used complies with Iraq's **(IQS No. 45/1984)** chemical and physical standards, as shown in **Tables 4** and **5**.

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	99.5	90-100
10	64.7	50-85
5	2.4	0-10

Table 5. Physical and chemical properties of coarse aggregate

Properties of gravel	The test result of the gravel	Limits of IQS No. 45/1984
Specific gravity	2.654	-
Absorption	0.6%	-
SO_3	0.05%	≤ 0.1%
Dry rodded density	1642 kg/m^3	-

2.1.4 Mixing Water

Use of potable water for mixing and curing, confirmed with the Iraqi standards **(IQS1703/1992)**.

2.1.5 Silica Fume

According to **(ASTM C1240-15**) having an activity index of 118 percent, silica fume (SF) from Sika Company Iraq conforms to this standard. **Tables 6** and **7** Provide technical details about silica fume.

Table 6. The physical tests of silica fume (SF)

Physical properties	Test results*	ASTM C- 1240Specification
Percent Retained on 45-µm (No. 325) sieve	8	≤10
Accelerated Pozzolanic strength Activity Index with Portland cement at 7 day	118	≥105
Specific surface m^2/g	16	≥15

Table 7. The chemical analysis of silica fume (SF)

Oxide Composition	Test results*	ASTMC1240 Specification
SiO_2	92.82	≥85.0
Moisture Content %	0.34	≤3.0
Loss on Ignition	1.59	≤6.0

* Given by the manufacturer.

2.1.6 Superplasticizer

Superplasticizer additive of the highest caliber for concrete. (Sika Viscocrete -5930L), A third-generation superplasticizer was used to provide perfect cohesion, improved flowability, and a significant decrease in water content by **ASTM-C494** Classes G and F. When the w/c ratio falls, a superplasticizer is used to enhance certain qualities of concrete and prevent flaws such as honeycombing by increasing the cement paste's permeability. In this experiment, cement and superplasticizer were combined in a weight-proportional amount. The technical description of the superplasticizer is given in **Table 8.**

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)	None that are known to be dangerous.
Odor	None
Density	1.3 kg/Lt
Labeling	No warning label is needed.
Chloride content	None
Poisoning	Non-toxic with applicable health and safety regulations
Dosage	(0.2- 0.8)%by weight of cement
Appearance	Turbid liquid

2.1.7 Copper Wire Fiber

Several electrical and electronic device applications use copper wire, a sustainable fiber, such as refrigerators and other appliances, all computer attachments, and the windings of electrical machines. The fiber used had an aspect ratio of (20, 40, 60, and 120) and measurements of (10 and 30) mm in length and (0.5 and 0.25) mm in diameter.

2.2 Selection of Mix Proportions for the Reference Concrete

Several test mixtures were created depending on the **(ACI 211 4R-08)** in addition to the already available Literature on High Strength Concrete Mix Design are used to attain a minimum compressive strength of 65 MPa after 28 days with high range water reduction additive (HRWRA) **(Annadurai and Ravichandran, 2014)**. These experimental combinations must either alter the amount of cement and the percentage replacement of silica fume or the amount of superplasticizer to achieve an identical design strength of 65 MPa at age 28 days. In this experiment, **Table 9** shows that silica fume weighing 15% of cement results in the highest strength. The cement, sand, and gravel mixture has a weight-to-volume ratio of 1:1.5:2.4, a cementitious content of 450 kg/m^3, a w/cm ratio of 0.31, and a slump value of (50-100) mm. For reference mix, the optimal HRWRA dose is 3.5 liters per 100 kg of cement. Copper fibers (1%) were added to the mixture, and SF (15%), respectively.

Table 9. Details of mix design for concrete mixes. (Cement Content is 382.5 kg/m^3), with sand, gravel, and SF densities of (700, 1100, and 67.5) kg/m^3, respectively.

Mix Symbol	Sp. L/100 kg	w/b	Fiber Length mm	Fiber Dim. mm	Fiber Aspect ratio
MR (Reference Mix)	0.8%	0.31	0	0	0
MF1 (1%fiber)			10	0.5	20
MF2 (1%fiber)			10	0.25	40
MF3 (1%fiber)			30	0.5	60
MF4 (1%fiber)			30	0.25	120

2.3 Preparation of Concrete Specimens and curing

Oil was used to lubricate and clean the interior surfaces of the steel molds to prevent concrete from sticking once it had dried. Layers of concrete were placed on the molds and then compressed using a vibrating table by **ASTM C192/C192M** for ample time to release any trapped air. To maintain a steady humidity level for roughly 24 hours, the specimens were compacted, leveled by hand troweling, and covered with a nylon sheet. Before the test's execution, the samples were removed from the molds and cured. Each concrete mix's compressive strength is measured using cube (100×100×100) mm specimens. For the splitting tensile strength test, a cylinder of (150 mm x 300 mm). (100x100x400) mm was used as the prism for flexural strength. In addition, water was used in a laboratory setting to cure all specimens **(ASTM C192/C192M-1)**.

2.4 Testing of Hardened Concrete

2.4.1 Compressive Strength Test

The compressive strengths of the concrete mixtures were measured using (100x100x100 mm) cubes in line with British Standard (**BS 12390-3)**. Before being put into the compression device, each concrete cube was thoroughly cleaned on all sides. This was done to ensure that the compressive load would be given steadily and perpendicularly to the direction that concrete would be poured into the molds. The University of Baghdad's Building Materials lab served as the testing location for this experiment. The compressive strength for each cube is derived by dividing the applied area of the load by the failure load. Three cubes, on average, were taken for each mix when the cubes were evaluated at ages 7, 28, and 60 days.

2.4.2 Flexural Strength Test

The flexural strength was assessed in the labs of the Civil Engineering Department according to (**ASTM C 293-02)** using the center point method. Prisms were analyzed, and an average of three prisms were obtained for each combination at 7, 28, and 60 days. The prism specimens in this experiment were supported with a 300 mm span. The formula was used to determine the rupture modulus.

$$\text{Fr} = \frac{3PL}{2bd2} \qquad (1)$$

where:

Fr: Flexural strength (MPa).
P: Largest load indicated by the machine under test. (N).
L: average specimen length (mm).
b: mean specimen width (mm).
d: Average depth of specimen (mm).

2.4.3 Splitting Tensile Strength Test

In this test at the Civil Engineering Department labs, concrete cylinder specimens of (150 mm x 300 mm) splitting tensile strength were determined using the compressive machine in line with **(ASTM C 496-04)**. This testing process would compress a concrete cylinder specimen diametrically down its side until tensile failure occurred. The compressive machine's steel plate evenly distributes the applied load over the cylinder's length. The cylinders were evaluated at ages 7, 28, and 60 days, after which the three-cylinder average was calculated using the calculations below.

$$\tau = \frac{2P}{\pi LD} \tag{2}$$

where
τ: Splitting tensile strength (MPa).
P: Max. Applied load (N).
L: Length (mm).
D: Diameter (mm).

3. RESULTS AND DISCUSSION

3.1 Compressive Strength

The compressive strength of hardened concrete, which is strongly related to other physical characteristics, is one of its most crucial attributes. **Table 10 and Fig. 1** display the findings of compressive strength tests performed on cubes of all concrete mixtures at 7, 28, and 60 days. Superior-quality concrete (HSC) must now be created using silica fume (15%) Due to major changes in the cement paste-aggregate interfacial zone. By increasing the density of the interfacial zone, the incredibly tiny particles that make up silica fume strengthen the binding between cement pastes and aggregate **(Atcin and Mindess, 2011)** and come to the same conclusion. The concrete sample with copper fiber reinforcement was stronger than the reference (MR) mix. This may be attributed to copper fiber's function plays in creating compressive strength, which acts as a barrier to stop or delay the occurrence of cracks up to a certain percentage of fiber (1%), as adding more fiber would result in non-homogeneous mixing and the formation of weak points that would reduce compressive strength The same conclusion were reached by **(Suhirkam et al., 2020).** When copper fiber was added to high-strength concrete, the development in compressive strength rose by 23%, 16%, and 17% for 7, 28, and 60 days, respectively, and higher than MR (high-strength concrete with no fiber). As shown by the findings in **Table 11**, for 7, 28, and 60 days, the compressive strength increases when the fiber aspect ratio increases by (2%, 1.7%, and 1.9%). Fibers of copper with a huge aspect ratio have greater compressive strength and prevent cracks from forming. On the other hand, low aspect ratio copper fibers can only halt the propagation of microcracks **(Köksal et al., 2008; Biswas et al., 2021)** and reach a comparable conclusion.

Table 10. Results of the Compressive Strength test

Mix Symbol	Compressive strength (MPa)			Fiber Aspect ratio
	7 Days	28 days	60 days	
MR	44.8	65.2	67	0
MF1	53.8	74.3	77	20
MF2	54.4	74	77.6	40
MF3	54.2	75	78.2	60
MF4	55	75.6	78.5	120

Table 11. The difference in the Compressive Strength test between MF4 and MF1

Mixes	Fiber Aspect ratio	Age (Days)		
		7	28	60
MF4	120	55	75.6	78.5
MF1	20	53.8	74.3	77
Increasing %		2%	1.7%	1.9%

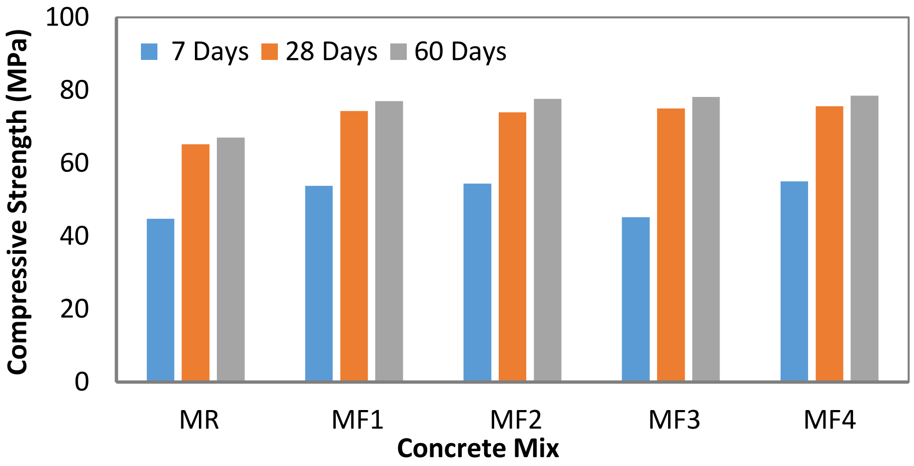

Figure 1. Compressive strength test results.

3.2 Flexural Strength

The flexural strength test procedure evaluates the response of materials under simple beam loads. Prisms with dimensions of (100x100x400) mm were employed for the test at different ages (7, 28, and 60 Days). **Table 12** and **Fig. 2** present the outcomes of flexural strength testing for concrete mixtures. The concretes were enhanced with copper fibers and silica fume, which significantly increased their flexural strengths. Concretes prepared with both silica fume and copper fiber performed better than concretes made with only silica fume. It was found that silica fume and copper fiber appeared to more significantly affect flexural strength. Although present in high concentrations, silica fume significantly increased flexural strength. All of these concur. **(Bhanja and Sengupta, 2005)**. The enhancement in flexural strength is due to the fibers' capacity to contain and span cracks. The results demonstrate that concrete mixes with high aspect ratios have stronger flexural properties than those with low aspect ratios. Compared to mix MF1, the flexural strength of mix MF4 rose by around 23%, 11%, and 12.6% for 7, 28 days, and 60 days, respectively **Table 13.** This supports the idea that longer, thicker fibers are more successful at preventing the formation of cracks. These agree with **(Köksal et al., 2008; Yu et al., 2014; Park et al., 2017).**

Table 12. Results of Flexural Strength

Mixes	Flexural Strength (MPa) Age (Days)			Fiber Aspect ratio
	7	28	60	
MR	7.2	9.67	10.4	0
MF1	7.8	11.8	12.6	20
MF2	8.6	12.4	13.7	40
MF3	9.1	12.6	13.3	60
MF4	9.6	13.1	14.2	120

Table 13. The difference in Flexural Strength between MF4 and MF1

Mixes	Fiber Aspect ratio	Age (Days)		
		7	28	60
MF4	120	9.6	13.1	14.2
MF1	20	7.8	11.8	12.6
Increasing %		23	11	12.6

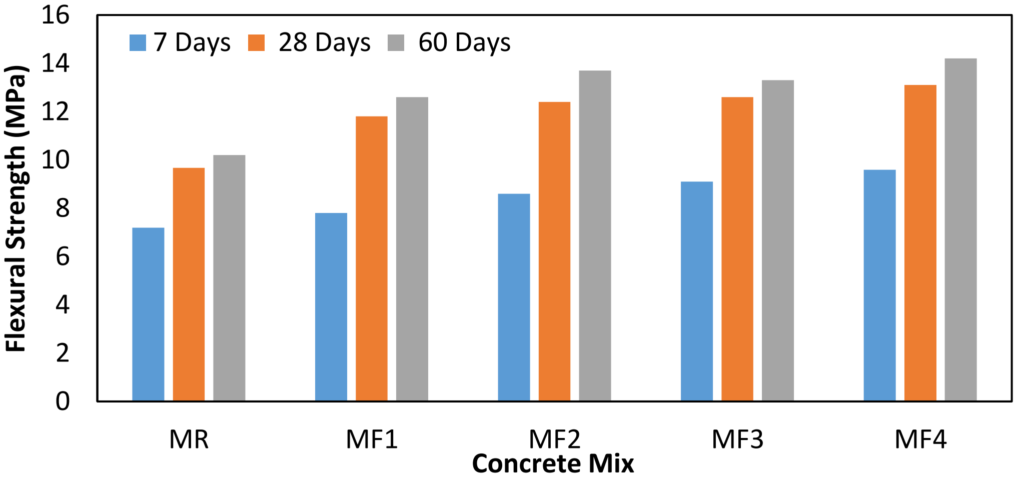

Figure 2. Flexural Strength test results

3.3. Splitting Tensile Strength

Table 14 and **Fig. 3** present the results of the splitting tensile strength tests for concrete mixtures. Adding copper fibers and silica fumes enhanced the concretes' splitting tensile strengths considerably. Concrete created with copper fiber plus silica fume performed better than concrete manufactured solely with silica fume. The fibers significantly contribute to the increase in splitting tensile strength by preventing microscopic cracks in concrete composite from escalating to macroscopic cracks and by allowing tension to be transferred from one end to the other without separating, pulling out, or breaking from the matrix, agreeing with study **(Vignesh et al., 2014)**. The capacity of copper fiber to bridge cracks and prevent them from expanding, in contrast to concrete, which includes no fiber, played a crucial role in enhancing split tensile strength performance. The findings show that concrete mixes with high aspect ratios have higher splitting tensile strengths than mixes with low aspect ratios. For example, mix MF4's splitting tensile strength rose roughly (1.7, 1.5, and 1.6 %) for (7, 28, and 60 days) compared to the MF1 **Table 15**. Because of the concrete bonding surface between the copper fibers and the concrete matrix, a higher aspect ratio of copper fibers could increase flexural and split tensile strength while maintaining the fiber %, in agreement with the study **(El-Din et al., 2016)**.

Table 14. Results of Splitting Tensile Strength test

Mixes	Splitting Tensile Strength (MPa) Age (Days)			Fiber Aspect ratio
	7	28	60	
MR	4.85	6.82	7.1	0
MF1	6.76	9.68	9.9	20
MF2	6.82	9.72	9.95	40
MF3	6.85	9.74	10	60
MF4	6.88	9.83	10.06	120

Table 15. The difference in the Splitting Tensile Strength test between MF4 and MF1

Mixes	Fiber Aspect ratio	Age (Days)		
		7	28	60
MF4	120	6.88	9.83	10.06
MF1	20	6.76	9.68	9.9
Increasing %		1.7	1.5	1.6

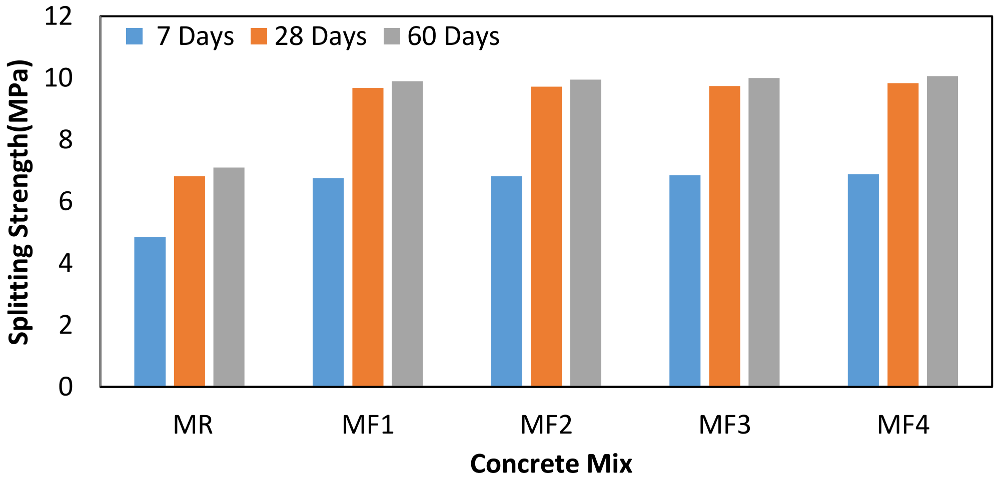

Figure 3. Splitting Tensile Strength test results.

4. CONCLUSIONS

Sustainability is the solution to pollution of all kinds, such as the CO_2 emissions from cement manufacture, which have detrimental impacts on society, the economy, and the earth. And we found that using copper fiber enhanced the mechanical properties of concrete, especially the fiber with a high aspect ratio. Based on the outcomes of the experiments, the current study's key findings are as follows:

- One of the finest alternatives to conventional concrete is high-strength green concrete, made from limestone cement and silica fume as replacements. It is reinforced with copper fiber as a sustainable fiber and has other qualities that make it superior to conventional concrete.
- For concrete mix with an aspect ratio (120) in 7, 28, and 60, the compressive strength increases for high aspect ratio concrete are 2%, 1.7%, and 1.9%, respectively, compared with a mix with a low aspect ratio (20). Through these results, it is clear that using sustainable copper fibers with a high aspect ratio led to a significant increase in the compressive strength of concrete.
- At all ages, the flexural strength of the high-strength green concrete with fibers that had a higher aspect ratio (120) was (23%, 11%, and 12.6%) times stronger than the concrete with fibers that had a lower aspect ratio (20).
- It was also shown through the results obtained from this examination that the use of copper fibers with a large aspect ratio led to an increase in the Splitting tensile strength of the concrete samples compared to the samples in which fibers with a small aspect ratio were used and for ages (7,28,60) days.

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