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Investigating Some Properties of Hybrid Fiber Reinforced LECA Lightweight Self-Compacting Concrete

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ABSTRACT

The primary goal of this investigation is to study the effect of using mono and hybrid fibers on the fresh and hardened characteristics of LightWeight Self-Compacting Concrete (LWSCC). Slump flow test, L-box test, sieve segregation test, and V-funnel test were used to evaluate the workability of LWSCC. The mechanical characteristics of LWSCC were assessed by using compressive strength, splitting strength, and flexural strength. Four mixtures using two types of fiber: Steel fiber (St) and polypropylene fiber (PP) (0% fiber, 1% (St), 0.75% (St) +0.25% (PP), 0.5% (St) +0.5% (PP)) were made. According to the results, (St) fiber and hybrid fiber addition to LWSCC reduced its workability, although the values of tests were still within the acceptable range stander of EFNARC. The findings indicated a decrease in the values of slump flow and L-box test by adding mono and hybrid fibers to the LWSCC mixture. While the T_{500mm} and V_ funnel tests increased by adding mono and hybrid fibers to LWSCC mixture. The results also indicate that the utilisation of (St) fiber and hybrid fibers had a significant effect on the mechanical characteristics of LWSCC. Where the flexural and splitting strengths significantly increase with the addition of (St) and hybrid fibers to the LWSCC mix.

Keywords: LECA, Hybrid fiber, Lightweight self-compacting concrete, Artificial aggregate.

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التحقيق في بعض خصائص خرسانة (الليكا) خفيفة الوزن ذاتية الرص المسلحة بالألياف الهجينة

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قسم الهندسة المدنية، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

الغرض الأساسي من هذا البحث هو دراسة تأثير أضافة الألياف الاحادية والهجينة على بعض الخواص الطرية والمتصلبة للخرسانة خفيفة الوزن ذاتية الرص(LWSCC) باستخدام الركام الخفيف الوزن (LECA). تم تقييم قابلية تشغيل لـ LWSCC باستخدام سلسلة من الاختبارات بما في ذلك اختبار جريان الهطول واختبار L-box واختبار فصل الغربال واختبار V-funnel. تم تقييم الخواص الميكانيكية لـ LWSCC باستخدام مقاومة الانضغاط ومقاومة الانشطار ومقاومة الانحناء. تم صب أربعة خلطات باستخدام الياف فولاذية والياف البولي بروبلين (0 الياف , 1% (St), 0.25% PP + 0.75% (St), 0.5 % (St)+ 0.5% PP) تشير النتائج إلى أن إضافة الألياف (St) والألياف الهجينة إلى LWSCC اثرت بشكل سلبي على قابلية التشغيل ، لكن نتائج الاختبارات ظلت ضمن حدود EFNARC. اظهرت النتائج نقصان قطر جريان الهطول وL-box بإضافة الالياف الاحادية والهجينة الى خليط LWSCC. ازداد زمن T_{500mm} و V- funnel بإضافة الالياف الى خليط LWSCC. كما تشير النتائج الى ان اضافة الالياف اثرت بشكل كبير على الخواص الميكانيكية. حيث أدت إضافة الياف الصلب والالياف الهجينة إلى زيادة كبيرة في مقاومة الانثناء والانشطار.

الكلمات المفتاحية: الليكا، ألياف هجينة، خرسانة خفيفة الوزن ذاتية الضغط (LWSCC)، مقاومة انضغاط.

1. INTRODUCTION

Lightweight concrete (LWC) is widely acknowledged for its ability to lessen the buildings' dead weight, reduce the area of sectional parts, and makes construction more convenient **(Rossignolo et al., 2003)**. One of the primary challenges for architects when working with concrete is the material's significant dead weight. One of the main problems of concrete structure engineers is the excessive dead weight of a building. Designers of concrete buildings must account for the significant dead weight of their creations. Researchers looked into ways to lessen the inert weight of concrete buildings by employing concrete with high compressive strength and low density **(Hayder et al., 2021)**.

It is common knowledge that Light-Weight Concrete (LWC) has many benefits over Normal-Weight Concrete (NWC), including a low density, low thermal conductivity, high strength to unit weight ratio, and good fire resistance. The utilization of LWC results in a decrease in the cross-sectional area of concrete elements and a reduction in the seismic loads generated, thereby reducing the possibility of building deterioration due to seismic **(Sarıdemir and Çelikten, 2020)**. The method of mix design for LWC differs greatly from that of conventional concrete. Segregation of aggregate would increase if the traditional mix design method was used, and the strength would decrease because of the decreased aggregate weight. To prevent these issues, it is suggested that lightweight concrete use the same mix design of Self-Compacting Concrete (SCC) **(Choi et al., 2006)**. SCC is a type of concrete that was first invented in the mid-1980s. There is no requirement for external vibration when using this type of concrete because of its exceptional self-flowing and mold-filling capabilities **(Hilal et al., 2021; Mazaheripour et al., 2011)**. This variety of concrete is capable of penetrating extensive areas and passing through the reinforcement without causing segregation between the mortar and coarse aggregate. Additionally, it enhances the durability of structures and reduces permeability **(Paratibha et al., 2008; Khaloo et al., 2014)**. Some of the advantages that SCC is expected to provide are the following: shorter building times, lower labor costs, lower noise pollution levels, and easy to fill congested and thin areas **(Anil, 2018)**. Many attempts have been made to combine two types of concrete into one type known as (LWSCC) to gain the advantages of both LWC with SCC **(Hilal et al., 2021)**. The utilization of Light Weight Aggregate (LWA) is crucial to the efficient production of LWSCC. LECA is one of the types of artificial lightweight aggregate which can be produced by heating clay particles at a temperature range from (1100-1200) ^{o}C in a rotary kiln. LECA can be employed to manufacture lightweight building materials including blocks and concrete as well as partition panels, tiles for thermal insulation and roofing plaster **(Banawair et al., 2019; Selman and Abbas, 2023)**. Since SCC mixes often contain more percentage fine ingredients than regular concrete, which might increase the likelihood of shrinkage and cracking. To delay the appearance of cracks and limit their spread, fibers are included in concrete to increase tensile and flexural strength **(Abdulhameed et al., 2018)**.

The impact of adding (St) and (PP) fibers and silica fume (SF) on the properties of (LWSCC) was investigated by **(Liu et al., 2019)**. All of the mixtures succeeded the workability test, indicating that they are LWSCC due to their high levels of fluidity, viscosity, and passing ability. The addition of (SF) and fibers enhance the mechanical characteristics of LWSCC. The impact of (St) on the characteristics of LWSCC in both its fresh and hardened condition was investigated by **(Al-Obaidey, 2020)**. The results indicate that adding (St) fiber to LWSCC diminished the workability. (St) had a slight effect on comp. strength, but their presence led to notable increases in splitting and flexural tensile strengths. **(Almawla et al., 2019)** investigated properties of (LWSCC) by using ponza as LWA. Ponza is used as a partial or complete replacement for conventional aggregate. Increases in filling capacity, T_{500mm} time, and passing ability were observed as ponza content was increased, whereas a reduction in resistance to segregation was observed. The results indicate a decrease in mechanical characteristics with an increase in the proportion of LWA (ponza).

(Ibrahim and Abbas, 2019) studied the effect of hybrid fiber on the properties of LWSCC containing pumice as LWA. Eleven LWSCC mixtures with different percentages of hybrid fibers were made. The findings suggest that increasing the proportion of (St) and PP fibers in LWSCC resulted in reduced workability in comparison to the reference mixture. Hybrid fibers enhanced the mechanical properties of (LWSCC). **(Gonen, 2015)** investigated the workability and mechanical qualities of LWSCC after adding (St). A decrease in workability was observed when fibers were added to LWSCC mixtures. The improvement in comp. strength was not as significant as that seen in the tensile strength tests. The effect of (St) fiber on the properties of SCC was studied by **(Abbas, 2013)**. Results showed that the fresh characteristics of SCC containing (St) exhibited a decrease in workability as (St) fiber percentage increased. In comparison to plain mix at all ages of curing, the tensile strengths of all fiber mixes were greater. As the number of fibers increased, so did the strength.

(Hachim and Fawzi, 2012) studied the influence of two types of LWA (Thermostone and Porcelinite) in the production of LWSCC, the effect of using silica fume (SF) and High Reactivity Metakaoline (HRM), and the effect of using various ratios of w/cm ratio (0.32) and (0.35) on the fresh and hardened properties of LWSCC. The results indicate that the air dry density of LWSSC of Porcelinit aggregate is 1964 kg/m^3 and the comp. strength is 29.57 MPa after 28 days with a w/cm ratio (0.32). The air dry density of LWSCC of thermostone aggregate is 1820 kg/m^3 and the comp. strength is 25.75 MPa at 28 days with a w/cm ratio (of 0.32). The results demonstrated HRM performs better than SF in LWSCC production
The principal aim of this work is to produce LWSCC by employing LECA as the lightweight aggregate and study the effect of adding (St) and hybrid fibers (St & PP) on the workability and mechanical properties of LWSCC.

2. MATERIA AND EXPERIMENTAL WORK

2.1 Utilized Material

2.1.1 Cement

OPC was utilized in this research (CEM I-42.5R. it's well-known commercially as (Mass) and it was produced in Iraq. The characteristics of OPC are given in **Tables 1** and **2**. The cement employed in this work conforms to the requirements of **(IQS No. 5, 2019)**.

Table 1. The chemical analysis of OPC

Oxides	Test results (% by weight)	Limit of **(IQS No.5, 2019)**
CaO	62.8	----
SiO_2	20.57	----
Al_2O_3	5.56	----
Fe_2O_3	3.32	----
MgO	2.91	5.0 (max)
SO_3	2.23	≤ 2.8% for C_3A > 3.5%
I.R	1.00	1.5 (max)
L.O.I	1.94	4.0 (max)
Main Compounds of OPC		
C_3S	50.79	---------
C_2s	20.74	---------
C_3A	9.12	---------
C_4AF	10.10	---------

2.1.2 Sand

Natural sand extracted from the Al-Ukhaidir region was utilized in this investigation. The sand complies with **(IQS No. 45, 1984)** standards.

2.1.3 Lightweight Coarse Aggregate (LECA)

LECA is an artificial light-weight aggregate made by burning clay particles with a low amount of lime in a rotating kiln at (1100-1200) C. LECA with a maximum size of 10mm was employed in this research. To obtain saturated surface dry (LECA) particles, they were soaked in water for one day before being added to concrete as shown in **Fig. 1**. The properties of LECA are given in **Table 3**.

Table 2. Physical Characteristics of OPC

Physical Characteristic	Test Result	Limits of **(IQS No.5, 2019)**
Specific surface area m^2/kg (Blain method)	381	≥ 280
Setting time (Vicat's apparatus)		
The initial setting, (min)	165	≥ 45 min
The final setting, (hr: min)	4:30	≤ 10 hr
Soundness (Autoclave method)%	0.14	≤ 0.8
Comp. strength (MPa) at 2-day	23	≥ 20
Comp. strength (MPa) at 28-day	44	≥ 42.5

Table 3. Characteristics of (LECA)

Characteristic	Results	Limits of **(IQS No 45, 1984)**
Specific gravity	0.65	----
Absorption,%	21	----
Bulk Density (loose), kg/m^3	320	----
SO_3	0.07	≤ 0.1

2.1.4 Silica Fume (SF)

In this investigation, SF had an activity index of 122%, making it suitable for partial cement replacement. SF meets the requirements of the standard **(ASTM C1240, 2014)**.

Figure 1. Lightweight Expanded Clay (LECA)

2.1.5 Limestone Powder (LP)

LP was utilized as an inert mineral filler to enhance the workability and resistance to segregation.

2.1.6 Superplasticizer

BETONAC1030, a polycarboxylate-based plasticizer, was used. The purpose of its use is to enhance workability and improve slump flow. Therefore, the resulting concrete has superior workability without segregation. The superplasticizer used in this study meets the **(ASTM C494, 2013)** specifications.

2.1.7 Water

The mixing and curing water used in this study must be clean, free of impurities, and conform to the **(IQS No.1703,1992)**.

2.1.8 Fiber used

In this study, kinds of fibers were used: polypropylene fiber (PP) and hooked-end steel fibers (St). **Table 4** and **Table 5** illustrate the properties of (St) and (PP) fibers respectively.

Table 4. The characteristics of (St) fiber

Appearance	Hook
Length	(35) mm
Diameter	(0.55) mm
l/d	64
The density of (St) fiber	(7800) kg/m^3
Tensile Strength of (St) fiber	(2200) MPa

Table 5. properties of (PP) fiber

Shape	Straight
Colours	White
Length of Fiber	(12) mm
Diameter of Fiber	(18) µm
Modulus of Elasticity	(4000) N/mm^2
Specific gravity	(0.91) g/cm^2

2.2 Mix Proportion

In this work, (LWSCC) mixes were designed to produce structural lightweight concrete that meets the criteria of **(EFNARC, 2005; ACI 213-R, 2003)** standards. As a result, many experimental mixtures were conducted to achieve those goals. In this investigation, four mixes with different fiber volume fractions were made. The fibers content of all four mixtures is demonstrated in **Table 6.** While the rest materials were constant in all mixtures. Where the weights of the materials were: (cement is 480 kg/m^3, silica fume is 80 kg/m^3, (LP) is 30 kg/m^3, the water is195 kg/m^3, sand is 800 kg/m^3, LECA is 150 kg/m^3 and w/b ratio was 0.34).

Table 6. Detail of Mixtures

Mixes	HRWRA% by wt. of binder content	(St) kg/m^3	(PP) kg/m^3
MR	1.6	0	0
M S	1.65	78	0
M SP1	1.71	58.5	2.275
M SP2	1.77	39	4.55

Where MR is the Reference mix, MS is the mix containing (St) fiber only, M SP1 is the mix containing hybrid fiber (0.75 % (St) + 0.25 % PP), and M SP2 is the mix containing hybrid fiber (0.5 % (St) + 0.5 % PP).

2.3 Method of Mixing

Since LECA has a high capacity for water absorption, it was submerged in water for 24 hours before being added to the mixture and then spread out in the laboratory **(Ketab and Nahhab, 2020)**. LECA were treated in this way to keep them from absorbing excess mixing water. In this work, the method of **(Doukakis, 2013; Abbas and Al Obaidey, 2016)** was used in the mixing of LWSCC. The steps of this method are as follows.

The process for mixing was as follows:

1. Fine materials including cement, silica fume and limestone powder are mixed in a bowl to ensure high homogeneity before adding them to the mixer.
2. LECA was added with (1/3) of the amount of mixing water to the mixer to be mixed for one minute.
3. The superplasticizer was added to the remaining water in the pail and mixed to ensure complete dissolve.
4. In the mixer, sand and the mixture of fine material were added, and then the mixtures of water with superplasticizer were added, after that the mixer was operated for three minutes.
5. Finally, steel and polypropylene fibers were gradually mixed into the mixture until a consistent distribution was achieved.

3. RESULTS AND DISCUSSION

3.1 Fresh Characteristics

3.1.1 Slump flow test

The test results for slump flow diameter are depicted in **Fig. 2-a** and **Table 7**. The values ranged between (650-760) mm for all mixtures. In accordance with **(EFNARC, 2005)** standards, all mixtures are acceptable. The slump flow diameter of LWSCC significantly decreases with added fibers in comparison to the control mix (without fiber). The incorporation of fibers results in an increase in flow resistance and a reduction in flow ability as a consequence of increased interlocking and frictional forces between the fibers and aggregate. While the T_{500mm} values varied between 2.1 and 3.7 seconds.

T_{500mm} values increased when fibers were used in LWSCC mixes. This was attributed to the increase in internal friction, as shown in previous research **(Ali and Hasan, 2020)**.

Table 7. The Test Results of Fresh Characteristics

Mixes	Slump flow (mm)	T_{500mm}	V-funnel (sec)	L-box	Segregation Index (SI)%
MR	760	2.1	7.0	0.98	18.3
MS	690	2.7	8.5	0.90	12.5
M SP1	675	3.2	9.7	0.85	9.2
M SP2	650	3.7	10.5	0.80	7.7

3.1.2 V-Funnel Time

Table 7 and **Fig. 2-b** detail the test results for the V-funnel. The values ranged from 7.0 to 10.5 seconds. According to the findings, the V-funnel flow time rises when fibers are included in the LWSCC mixture. The inclusion of fibers slows the flow rate through the V-funnel because the fibers obstruct the flow within the constrained region of the V-funnel. This was attributed to an increase in the viscosity factor of mixes, which led to concrete with more cohesion and interlocking as a result of the addition of fiber. These findings agree with **(Ibrahim and Abbas, 2019)**.

3.1.3 L-Box Test

Table 7 and **Fig. 2-c** detail the results of the blocking ratio (BR) (H2/H1) testing. The results of BR range between 0.8 and 0.98).
The results showed that the blocking ratio (BR) dropped after fibers were added to the LWSCC mixture. This is because the addition of fibers increases flow resistance and decreases flow ability as a result of increased interlocking and friction between fibers and aggregate.

3.1.4 Sieve Segregation Tests

Segregation resistance was measured by using a sieve test, as shown in **Fig. 2-d.** The test results of segregation resistance are shown in **Table 7**. According to the results, the concrete mixture without fibers has higher values. This is due to the distribution of fibres in concrete, which leads to the creation of a network that can effectively prevent aggregate particles from becoming separated from one another **(Almawla et al., 2019)**. All LWSCC mixtures have segregation values that are within the range recommended by **(ENFARC, 2005)**.

3.2 The Results of Hardened Properties

3.2.1 The Compressive Strength Test

This test was carried out according to **(BS EN 12390-3, 2019)**. **Table 8** and **Fig. 3** list the compressive strength of the various mixtures, including the reference mixture (without fiber), the mixture containing (St) fiber (MS), and the mixtures with hybrid fiber (0.75 (St) + 0.25 PP) and (0.5% (St) + 0.5% PP) at 7 and 28 days, respectively. At 28 days, the comp. strength of the mixture containing 1% (St) fibers increased by about 19% as compared to reference concrete (MR). Also, the compressive strengths of mixtures containing hybrid fiber (0.75 % (St) + 0.25 % PP) and (0.5 % (St) + 0.5 % PP) increased by approximately 14% and 7%, respectively, compared to MR. This is because hybrid fibers with varying sizes and kinds would provide a wide range of restriction conditions. These conditions may be related to the

Figure 2. Testing of fresh characteristics **(a)** slump flow, **(b)** V-funnel **(c)** L-box and **(d)** sieve segregation test

enhancement of the mechanical bond strength of concrete, where the fibers can both delay the creation of micro cracks and afterwards stop their spread to a certain extent **(Ali and Shakir, 2009; AL-Radi et al., 2021)**.

Table 8. The obtained mechanical properties of LWSSC

Mixes	Compresive strength, MPa		Splitting strength, MPa		Flexural strength, MPa	
	7 days	28 days	7 days	28 days	7 days	28 days
MR	19.2	25.6	1.68	2.5	2.5	3.9
MS	22.5	30.5	2.81	3.6	4.7	6.2
M SP1	21.4	29.2	2.55	3.4	4.2	5.8
M SP2	20.1	27.6	2.24	3.1	3.9	5.3

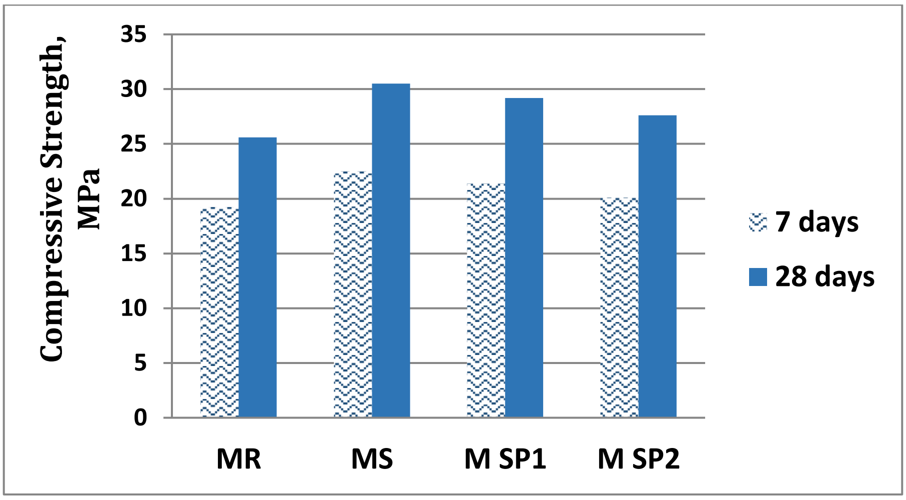

Figure 3. The compressive strength of reinforced LWSCC

3.2.2 The Splitting Tensile Strength Test

This test was conducted in accordance with **(ASTM C496, 2011)** standard**. Table 8** and **Fig. 4** illustrate the results of splitting strength at 7 and 28 days.

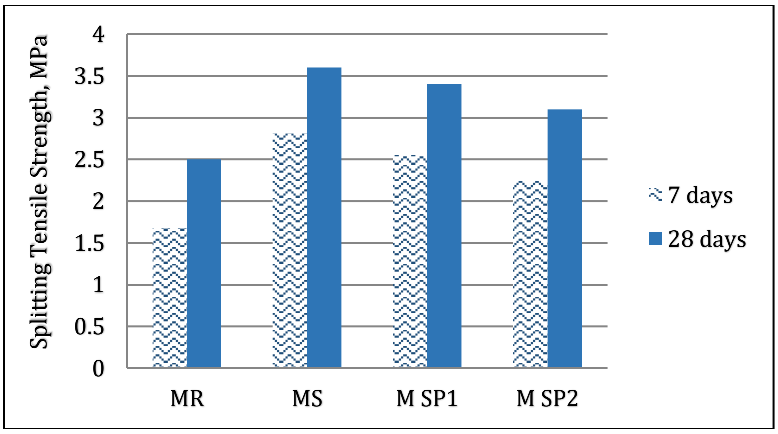

Figure 4. The splitting strength of reinforced LWSCC

The findings demonstrate the splitting strength of mixtures containing 1% (St) fiber (MS) increased by approximately 44%; mixtures containing hybrid fibers (0.75 % (St) + 0.25 % PP) and mixtures with (0.5% (St) + 0.5 %PP) increased by approximately 36% and 24%, respectively, as compared to reference fiber without fiber (MR). The addition of fibers is the reason for the increased strength. This is due to the fibers' mechanism in stopping crack growth and the improved fibre-to-matrix bonding.Furthermore, the pullout strength was significantly enhanced by the improved bonding of the fiber matrix, which could be achieved by the hooked ends of (St) fiber. As a result, the incorporation of fibers led to a considerable increase in strength.

3.2.3 The Flexural Tensile Strength Test

This test was conducted in accordance with **(ASTM C293, 2008)** standard. **Table 8** and **Fig. 5** show the flexural strengths at 7 and 28 days, respectively. The results indicate the flexural strength of mixtures containing 1% (St) fiber (MS) increased by approximately 59%; mixtures containing hybrid fibers (0.75 % (St) + 0.25 % PP) and mixtures with (0.5% (St) + 0.5 %PP) increased by approximately 48% and 36%, respectively, as compared to reference fiber without fiber (MR). This increase in flexural strength is because, following matrix cracking, the fibers will continue to bear the force that the concrete carried until cracking, due to the interfacial link between the fibers and the matrix. As a result, the load-bearing capacity increases since the fibers prevent cracks from spreading and do not break suddenly **(Khalil and Mozan, 2015)**.

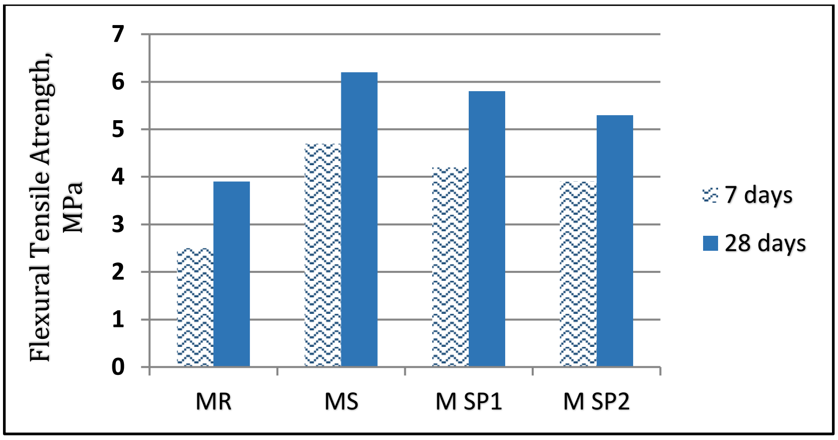

Figure 5. The flexural strength of reinforced LWSCC

4. CONCLUSIONS

The effect of mono and hybrid fibers on the workability and hardened properties LWSCC mixture has been investigated. The required goals are achieved and the target properties are improved. Based on the discussed results, the following can be concluded:

- All mixtures meet the requirements of **(EFNAR, 2005)** standards, but by adding (St) and hybrid fibers to LWSCC, the slump flow diameter of MS, M SP1, and M SP2 decreased by about 9.2%, 11.3%, and 14.6%, respectively, in comparison to control mix. Also, the L-Box test (blocking ratios) decreased with the addition of fibers. Where the blocking ratio decreased by about 8, 13, and 18% for MS, MSP1, and MSP2, respectively, in comparison to the control mix.
- The incorporation of (St) and hybrid fibers to LWSCC increased the slump flow time (T_{500mm}) by about (28, 52, and 76)% respectively, for (MS, MSP1, and MSP2). As well as the time of V-funnel flow increased with adding fibers by about (21, 38, and 50)% for (MS, MSP1, and MSP2), respectively in comparison to the control mix.
- The utilisation of (St) and hybrid fibers leads to a slightly improved comp. strength of LWSCC. Where the percentage increase in comp. strength at 28 days was about (19, 14, and 7%) for MS, MSP1, and MSP2, respectively, in comparison to control mix.
- All mixtures containing (St) fiber and hybrid fibers showed higher splitting and flexural strengths. When compared with the reference mixture (without fiber), the increase in

splitting strength at 28 days was about 44, 36, and 24 % for MS, MSP1, and MSP2, respectively. While the increase in flexural strength at 28 days was about 60, 48, and 35 percent for MS, MSP1, and MSP2, respectively.

- The highest splitting and flexural strengths were obtained when 1% of (St) fibers were added to the LWSCC mixture.

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