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IMPACT OF VARIOUS TYPES OF FIBRES ON THE MECHANICAL PROPERTIES OF LIGHTWEIGHT CONCRETE

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Abstract

Impact of various types of fibres on the Mechanical propertes of Lightweght Concrete. This research aims to study the effect of adding fibers on the fresh, and hard propertes of light concrete. To achieving this goal, 13 mixtures were examined, containing different types and proportions of fiber, where the precipitation was examined, as well as the compressive strength, the splitting strength, the fracture modulus , in addition to the workability . The basic variables for this research. The type of fibre, where four types of fibre (steel hooked end , crimped steel , glass, and polypropylene,) were used, and the second variable is the percentage of fibre, as the ratios were as follows (0.3, 0.5, 0.6, 0.8, 1, and 1.3) , As for the third variable, it was to combine the types of fibers with each other to obtain the hybrid fibre and study its effect on lightweghit concrete. The results showed that the mixing of steel fiber by 0.5 with the class by 0.5% with 0.3 polypropylene led to decrease the workability of mix , on other hand ,Compressive strength and splitting tensile strength , in addition to other properties of concrete were improved , where the percentage of increase in the compressive and splitting strength was 52.17 and 45.36 %, respectively. Furthermore, the hooked end steel showed a better performance than crimped steel in improving proprieties of lightweight concrete.

Keywords:

Glass fibre;
Lightweight-fibre concrete;
Hybrid fibre;
Tensile strength;
Workability.

1 Introduction

With the construction of huge and high concrete structures, concrete must perform better (e.g., workability, increased strength and toughness, and light weight) [1]. Concrete has significant compression and resistance characteristics. The use of normal weight aggregates, such as gravel and granite, has resulted in a decrease in natural rock deposits, and their continued exploration could cause environmental harm and ecological imbalance. It is therefore absolutely essential to find a suitable replacement material for the coarse aggregates used in the production of concrete [2]. Llightweight aggregate concrete (LWAC) outperforms normal weight concrete (NWC) in terms of fire resistance, earthquake resistance, and thermal insulation [3]. Utilizing lightweight concrete, such as foamed concrete or LECA, offers the advantage of reducing a structure's self-weight while simultaneously enhancing its fire resistance, sound insulation, and thermal properties in comparison to conventional concrete.[4] LWC refers to concrete containing an expanding agent and lightweight aggregate (LWA). Most lightweight aggregates (LWA) have higher water absorption ratings than normal aggregate.[5]. It has a dry density varying from 300 to 1,840 kg/m which leads to a weight reduction of 23% to 80% compared to that of normal weight concrete. For LWC used structurally, the unit weight ranges from 1,400 to 2,000 kg·m^{-3}, considerably lighter than typical weight concrete of 2,400 kg·m-3[5].LWAC has a greater strength-to-weight ratio than NWC (ACI Balendran et al., 2002; Committee and 213, 2014)[7]. As a result, LWAC may be used to design structural sections with a smaller cross-section and reduced weight. To compensate for the poor stiffness of LWAC used for structural applications, it's important to establish a high goal strength. However, an rise in concrete strength may product in high brittleness (Li et al., 2021)[8]. Adding fibres to concrete can reduce negative influnces and increase mechanical performance of LWAC (Hamoush et al., 2010) [9] .The mechanical properties of reinforced concrete with polypropylene hybrid fibers were studied by Hsie M. et al. (2008)[10]. They employed staple fibers and coarse monofilament as two types of polypropylene fibers. The former has contents of 3 kg/m^3, 6 kg/m^3, and 9 kg/m^3, whereas the latter has a level of 0.6 kg/m^3. Polypropylene hybrid fiber-reinforced concrete rose in compressive strength by 14.60–17.31%, splitting tensile strength by 8.88–13.35%, and modulus of rupture by 8.99–24.60% when compared to pure concrete's strengths. Concrete's toughness index can be raised by adding polypropylene hybrid fibers; the higher the fiber content, the higher the toughness index. (Ahmed et al., 2017)[11] evaluated the influence of several parameters, including fiber type and volume %.Three varieties of polypropylene with varying volume fractions were used.The process also comprises tests for compressive strength, splitting tensile strength, flexural strength, and static modulus of elasticity. The test findings demonstrate that the inclusion of all kinds of polypropylene fibre leads in a considerable increase in most mechanical parameters when compared to control concrete samples at various ages, with the exception of compressive strength, which was enhanced at volume fraction =0.25% and decreased at volume fraction=0.75%. Lee et al. (2019)[12] found that lightweight aggregates have poor strength, leading to fast cracks propagation and brittle fracture of concrete. Crack primarily flow through the aggregate particles, causing in localized failure regions. To achieve the desired performance of FRLWAC, various design choices (e.g., fibre sort, Vf and LWA sort, density, and water absorption) require a significant quantity of data on its mechanical characteristics.

(Yang et al., 2022)[13] investigated the effects of various steel fiber kinds and contents on the mechanical characteristics, workability, and augmentation of ductility of lightweight aggregate concrete (LWAC). At the intended compressive strength of 40 MPa, thirteen LWAC mixes were made using various types of steel fibres, containing straight (CSF(S)), crimp-shaped (CSF(C)), hooked-end (CSF(H)), and hooked-end macro steel fibres (SF(H)). The steel fibers were coated with copper. There was a 0.5% gap between the fiber volume percent of 0% and 1.5%. The results of the tests indicated that the CSF(H) kind has a greater potential than the other kinds for improving the toughness and tensile resistance of beams at the post-peak part of the load-defection curves. (Issa & Al-Asadi, 2022) [14] investigated the mechanical characteristics of concrete that completely replaced coarse aggregate with lightweght expand clay aggregate (LECA). The findings indicate that the reduced strength of the expanded clay (LWA) in the concretee with an valued compresive strength of 32 MPa was responsible for a greater fall in the strength of lightweght aggregate concrete (LWAC). Based of the test results, adding silica fume (SF) significantly enhanced the mechanical characteristics of LWC. Moreover, ASTM C330/C330M-17A minimam criterion for splitting tensile streangth is 47% lower in LECA concrete. The ratio of the LECA concrete's splitting tensile streangth to compressive strength is roughly 13%. The outcomes additionally show a 27% variation in the modulas of elasticity between the astimated and the tested values.

(Zaezue & Hadi, 2023) [15] investigate how ordinary concrete's workability, compressive strength, splitting strength, and modulus of elasticity are affected by hybrid steel-polypropylene fibers. Four mixes were made for this purpose, along with a standard concretee mixture for control. The percentages of steel and polypropylene fibre were 0.75 and 1.5%, respectively, and 0.15 and 0.3%, respectively. According to the results, the slump flow of all concrete combinations, containg hybrid fibre, was lower than that of the refrence mixture (0%).The compressive, splitting, and elasticity modulus of hybrid concrete with steel and polypropylene fibers were higher than those of other types of fiberless concrete. The hybridization ratio of 1.5% steel and 0.3% polypropylene produced the highest growth ratio in compressive and splitting stresses, according the test results.

(AL-KHAFAJI & HARBA,2023) [16] studied the shear and flexural behavior of lightweight concrete beams containing hybrid fibers.the main variables were included the type of fibers (steel and polypropylene) and the size of the added fibers 0 %, 0.05 %, 0.1 % for polypropylene fibers 0 %, 0.75 %, 1 % for steel fibers. The results showed that the workability of the concrete decreased with the increase in the percentage of steel fibers, as the higher the percentage of fibers, the more rigid the mixture, Lightweight, high-strength concrete was produced without fibers, as it reached a compressive strength *fcu*, 38 MPa at the age of 28., When comparing steel fibers with a length of 3, and 3.5 mm, it was found that there is a slight effect on the results of the mechanical properties. , The presence of fibers improves the compressive strength of the samples containing hybrid fibers, of P.P. by 0.1 % and S.F. by 1 %, and single S.F. by 1 %, with an increase of 30.1 % and 27.5 %, respectively. As for the effect of the mixtures on the tensile strength of the split, it had the highest effect when adding S.F. with the highest rate of 63.6 %, unlike when adding P.P. with the highest percentage of 0.1 %, the tensile strength of the split was decreased by 39.8 with a volume of 0.1 %, for S.F. by 1 %, and P.P. by 0.1 %, with an increase of 73.6 %, and 60 %, respectively.

This study aims to methodically ascertain the mechanical properties of thirteen fiber-light weight reinforced concrete mixes, each with varying proportions of steel, glass, polypropylene, and hybrid fiber combinations. The tests will be conducted to determine the mixes' slump, compressive strength, splitting tensile strength, and flexural strength.

2 Materials

Four types of fibers were used in current study. Two types of steel fibres (Hooked end steel and crimped steel fiber), fibrillated polypropylene, and Glass fiber were used in this work which are displayed in Figure 1 . In addition to mixing two different types of fiber to produce a hybrid fiber, four types of hybrid were used. The first type resulted from mixing steel fiber and polypropylene fiber, the second type resulted from adding steel fiber and glass fiber, and the third type produced from mixing polypropylene and class. The last type was a mixture of three types of fiber (polypropylene, glass and steel fiber). The properties of the fibers are registered in Table 1.

Type V sulfur-resistant portland cement was used, which complies with ASTM C150/C150M-21 standard (ASTM, 2021). High-range water-reducing Sika® ViscoCrete®-5930 super plasticizer (SP) in accordance with ASTM C494/C494M-19 standard (ASTM, 2019) standards was applied to the material to make it more workable. The ASTM C33/C33M-13 standard (ASTM, 2013)-compliant fine aggregate with a maximum size of(4.75 mm) was employed in this investigation. In this investigation, the LECA was utilized as a lightweght aggregate in all LWC mixes, with a maximum size of(10 mm). In this investigation, the coarse aggregate was completely replaced with expand clay aggregate, as seen in figure 2. Values of silica fume that met ASTM C1240-05 standards (ASTM, 2005) were employed.

Fig. 1: Type of fiber: a – single fibre , b – hybrid fibre

Table 1: fibers properties

Fiber	Steel (SF)	Polypropylene	Glass fiber
Length (mm)	35	12	20
Diameter (mm)	0.5	0.032	-
Aspect Ratio L/D	70	375	-
Geometry	Hooked-End	Straight	Straight
Tensile Strength (Mpa)	1150	(600-700)	

Fig. 2: LECA used in This current study Title

Mix design

The control mix was design to have a cube compressive strength of 23 MPa, in accordance with the BS 1881-116 standard (British Standards Institution [BSI], 1991). Thirteen mixes was cast .Each sample mix design has different volumetric ratio of fibers . Table 2 shows the mixture proportions that were used in this research.

Table 2: All used mixes proportions

Mix	Cemnt	Sand	LECA [kg·m3]	Water	Super plasticizer [%]	Vf of SF [%]	Vf of GF [%]	Vf of PPF [%]	Total Vf of fbers [%]
M1	460	936	180	190	1.25	0	0	0	0
M2						0.5(hook end)	0	0	0.5
M3						1 (hook end)	0	0	1
M4						0.5(crimped)	0	0.	0.5
M5						1 (crimped)	0	0	1
M6						0	0.5	0	0.5
M7						0	0.9	0	0.9
M8						0	0	0.3	0.3
M9						0	0	0.6	0.6
M10						0.5	0	0.3	0.8
M11						0.5	0.5	0	1
M12						0	0.5	0.3	0.8
M13						0.5	0.5	0.3	1.3

[a]SF=steel fiber, GF=glass fiber ,PPF=polypropylene fiber

Casting and curing of samples

Standard cube 150 x 150 x 150 mm were used in agreement with BS 1881-116 (BSI, 1991) to conclude the concrete's compressive strength. Standard cylinders 150 x 300 mm were used, according to ASTM C496/ C496 M-11 (ASTM, 2004), for obtaining tensile strength. To prevent moisture loss, the samples were coated with polyethylene sheets. After 24 hours of pouring, the specimens were demolded and put in an outfitted tank. Prisms of 150 x 150 x 500 mm were poured, maintained wet, and immersed in water under the same circumstances as the compressive strength samples. After 28 days, the samples were examined. Figure 3 shows casting and curing.

Fig. 3: casting and curing of samples

Test method

Workability test (slump)

To investigate the influence of fibers existence in fresh lightweight concrete and investigate the change in consistency and workability, a slump test was achieved. Tests were observed depended on ASTM C143/C143M-15 (ASTM, 2015b). All the mixtures, control mixture, and mixture that comprises fibers were placed and compressed by a steel rod in the cone. Figure 4 shows slump test.

Fig. 4: Slump test

Test of compressive strength (fcu)

The cube samples were tested using a digital compression machine with a 2,000 kN capacity. Three samples were evaluated, and the tests were carried out at 28-days of age. The higher bearing block's center of thrust is precisely where the sample is positioned, and loading is applied continually until the sample fails. The mean of three samples was determined. The shape of failure and compressive strength test are presented in Figure 5.

Fig. 5: cubes specimens test and failure shapes

Cylinder splitting test

Tensile strength was determined using standard cylinders 150 x 300 mm, as specified in ASTM C496/ C496 M-11 (ASTM, 2004). Following 24 hours of pouring, the samples were demolded and sited in the curing container. After 28 days, the samples were analyzed till the splitting load was determined. The average value of the three cylinders is evaluated. Figure 6 depicts the split strength test

Fig. 6: splitting strength test

Test of flexural strength

Flexural strength is evaluated using the results of a third-point loading prism test in agreement with ASTM C78/C78M--15A (ASTM, 2015a) .an experienced prisms (150 x 150 x 500 mm) were poured, maintained wet, and immersed in water under the similar circumstances as the compressive strength samples. Figure 7 shows the sample test and failure shapes.

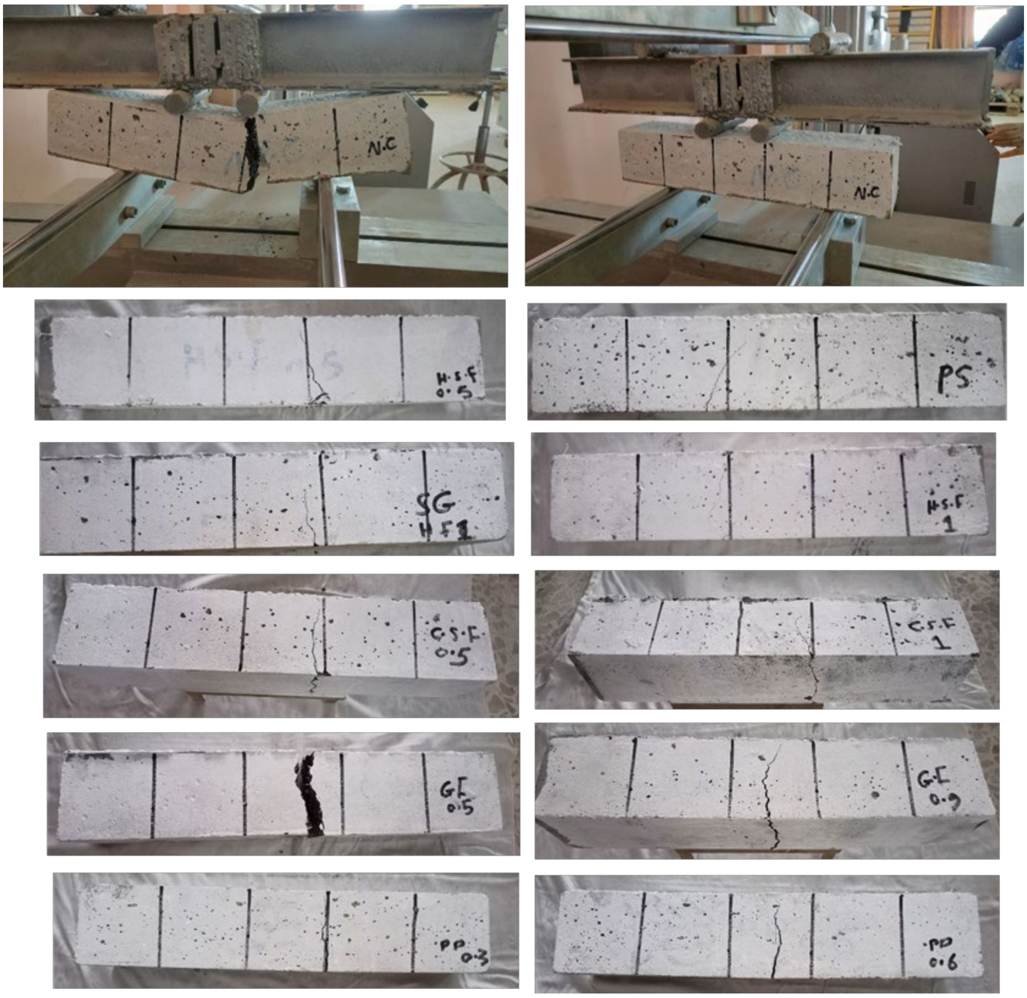

Fig. 7: prism specimens test and failure shapes

Results and discussion

Workability and Compressive strength

The slump values and compressive strengths are listed in Table 3, In terms of slump, all mixes showed slump flows in the range of 85-10 mm. There was dropped in slump value with adding of fibers and there was decreasing in slump value with hybrid fiber 1.3% . Figure 8 displays the slump value of various mixes. The fibres (crimped steel (0.5%), Hook end steel (0.5%) and polypropylene 0.3%) showed better slump values

Table 3: Workability and Compressive strength

mix	Total volumetric ratio of fbers [%]	Slump value [mm]	decrease Compared to Control mix [%]	Average Compressive strength fcu	Increase Compared to Control mix [%]
M1	0	85	0	23	0
M2	0.5	40	52.94	29	26.08
M3	1	20	76.47	32	39.130
M4	0.5	45	47.05	28	21.73
M5	1	20	79.26	30.67	33.34
M6	0.5	25	70.588	28.2	21.7
M7	0.9	10	88.23	30.23	33.34
M8	0.3	45	47.05	26.83	16.65
M9	0.6	30	64.70	28	21.73
M10	0.8	25	70.588	32.4	40.86
M11	1	10	88.23	31.8	38.26
M12	0.8	15	82.35	30	30.43
M13	1.3	20	76.47	35	52.17

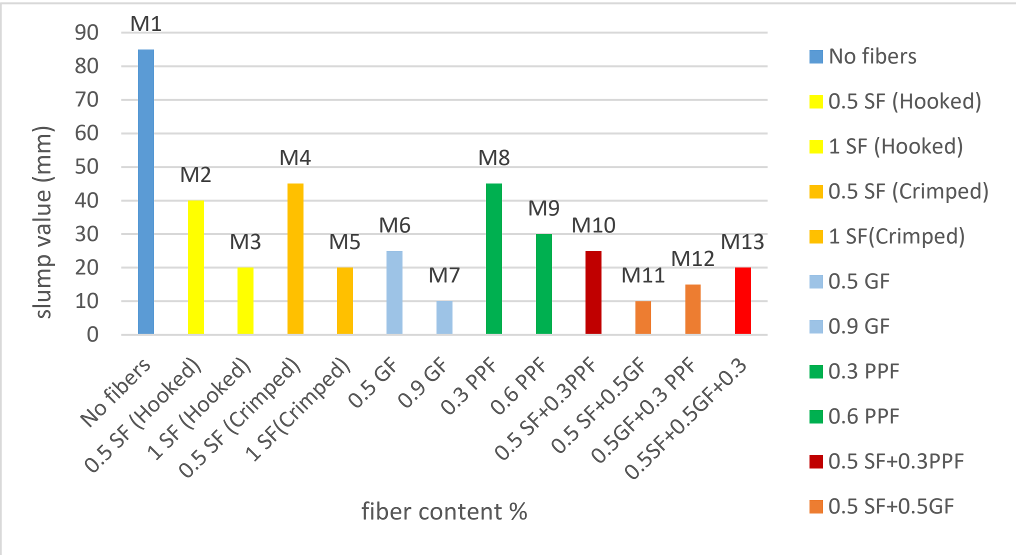

Fig. 8: slump value

For steel fiber types (Hook end and crimped) with the fibres ratios of (0.5%,and 1%), the compressive strength was raised to the reference mix by (26.08 and 39.13) , and (21.73and 33.34) %, respectively. The outcomes display that the best type for increasing compressive strength was the hook end steel fiber for single fiber while for hybrid the best type was the (hook end steel +glass + polypropylene). Figure 9 shows Compressive strength and increase of Compressive strength.

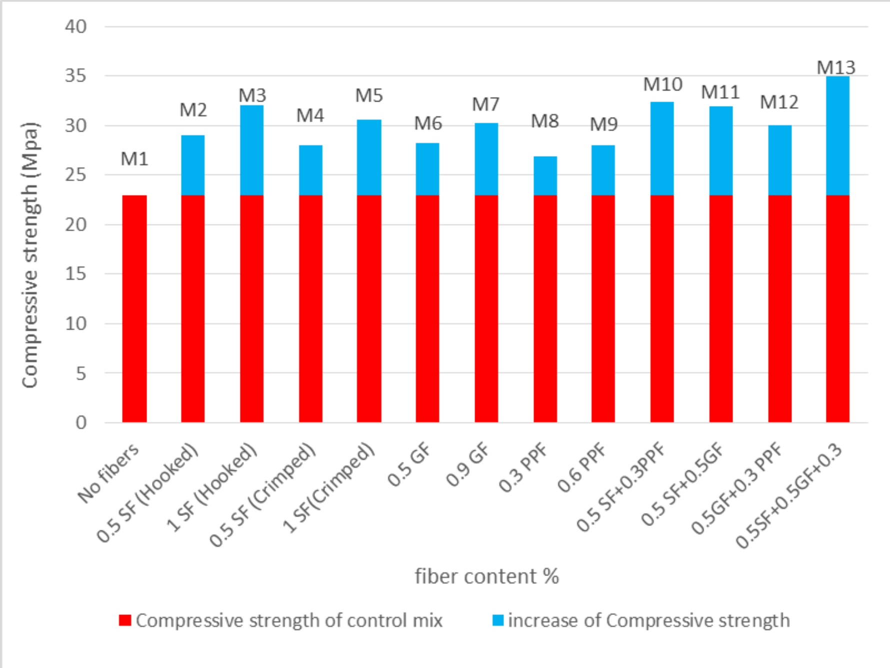

Fig. 9: Compressive strength and increase of Compressive strength

Cylinder splitting test and Modulus of rupture (fr)

Spliting tensile stress and Modules of rupture are recored in table 4 . In general, adding fibers to the lightweghit concrete mix led to increase in splitting strength and Modulus of rupture (fr) . This increase varies according to the type and percentage of added fiber, as the highest percentage of increase in tensile strength was 45.85 and was obtained when steel fiber was added at a rate of 1. The highest percentage of increase in the modulus of fracture was 250% and was also obtained from adding steel fiber to the concrete mix at a rate of 1% . As for the type of fiber that had the least effect on tensile strength, it was class fiber at a rate of 0.5%. Figure 10 shows the tensile strength, while polypropylene fiber was the type that had the least effect on the modulus of fracture, as the increase rate was 16.4%. Figure 11 shows the bending resistance.

Table 4: Cylinder splitting strength and Modulus of rupture (fr)

mix	Total volumetric ratio of fbers (%)	Spliting tensile stress (Mpa) fsp	Increase Compared to Control mix %	Modules of rupture (Mpa) fcr	Increase Compared to Control mix %
M1	0	2.05	0	4.13	0
M2	0.5	2.532	23.512	12.054	191.8
M3	1	2.99	45.853	14.47	250.3
M4	0.5	2.48	20.97	7.24	75.3
M5	1	2.86	39.512	9.88	139.2
M6	0.5	2.122	3.151	5.08	23
M7	0.9	2.603	26.97	5.09	232
M8	0.3	2.334	13.85	4.81	16.4
M9	0.6	2.7	31.7	5.415	31.1
M10	0.8	2.829	38	13.1	217.19
M11	1	2.886	40.7	13.5	226.87
M12	0.8	2.43	18.53	6.105	47
M13	1.3	2.98	45.365	13.8	234.14

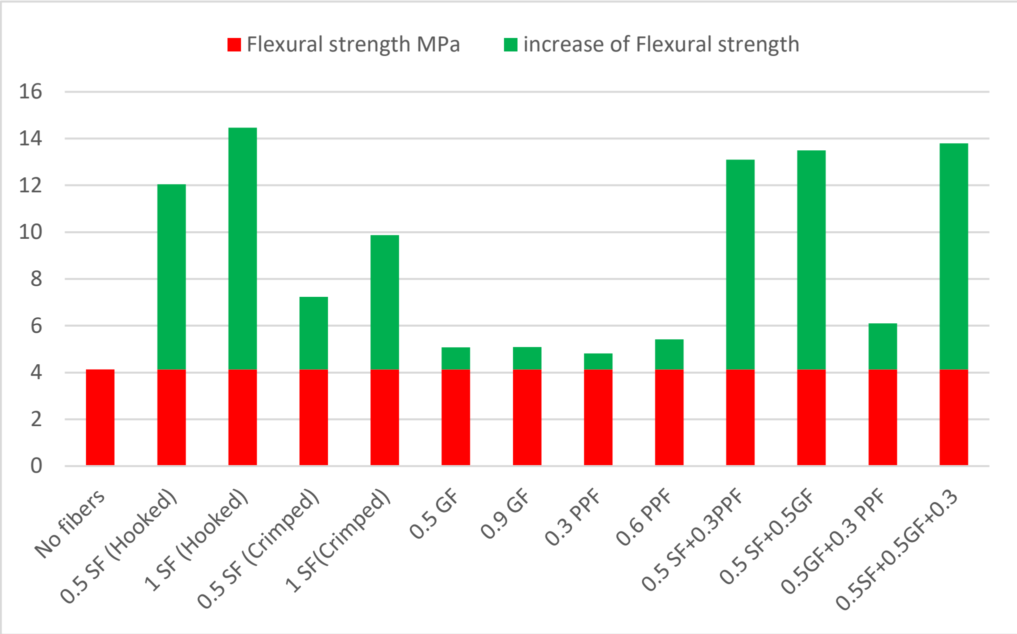

Fig. 10: Splitting strength and increase of splitting strength

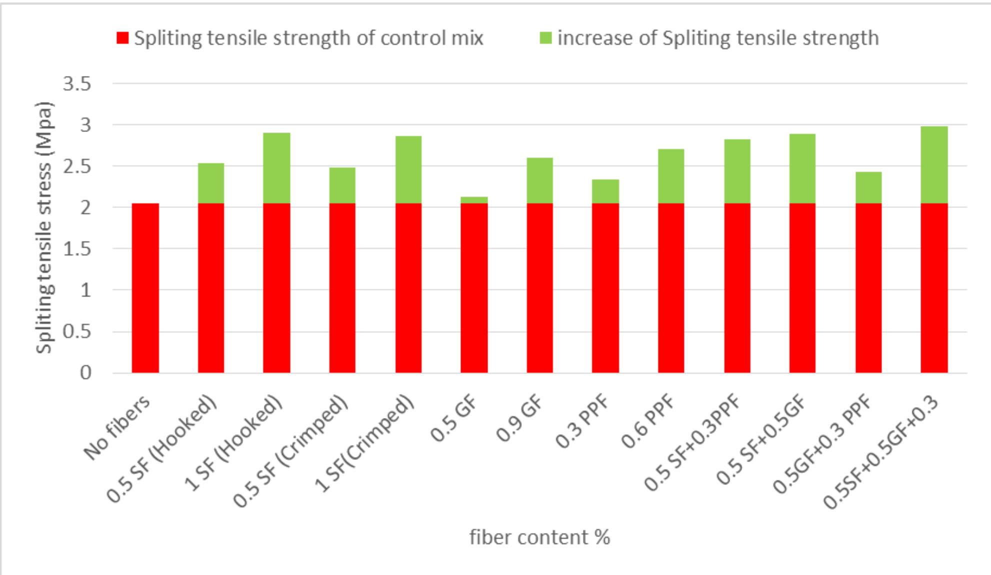

Fig. 11: Flexural strength and increase of flexural strength

Conclusions

This paper investigated the influence of different fibers on fresh and Harding properties of lightweight concrete. according to the results obtained in the present study, the following conclusions can be drawn:

1) The addition of fibers reduced the workability of concrete and shows a stiffer nature of concrete .

2) Polypropylene fiber has lower workability compared to other single fibers.slump value of polypropylene fiber concrete with fiber aspect ratio 0.9 decreases 88.23% than that of concrete without fiber.

3) Combining two types of fiber completely reduces the workability than adding the fiber separately, as the percentage of decrease when using steel with a percentage of 0.5 % and class with a percentage of 0.5 % is 52.94 and 70.58 %, respectively, but when mixing the two types together and in the same percentage, the decrease in length becomes 88.23 %.

4) Adding fibers in different proportions and types led to an increase in the mechanical properties of light concrete, where the increase in compressive strength ranged between (16.65-52.17%), while the maximum increase in tensile strength was (45.85%). On the other hand, the percentage increase in the fracture modulus ranged between (23-250%)

5) The maximum percentage increase in compressive strength is 52.17% resulting from combining 0.5% steel fiber with 0.5% class and 0.3 % polypropylene, while the maximum tensile strength was obtained when adding 1% steel fiber.

6) Hook end steel fibers provide a notable inhancment to the concrete at 1% addition contrasted to other types.

7) The highest percentage increase in the modulus of fracture was obtained when adding hook end steel at a rate of 1%, while the lowest increase in the modulus of fracture was when adding polypropylene at a rate of 0.3%.

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