Research Article

Behavior of foamed concrete reinforced with hybrid fibers and exposed to elevated temperatures

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Abstract

This paper demonstrates the behavior of foamed concrete reinforced with either or both carbon fibers and polypropylene fibers exposed to elevated temperatures. Various volumetric fractions of carbon fibers (0.5, 1 and 1.5%) were used to reinforce foamed concrete mix. Also, hybrid fibers of carbon fibers (CF) and polypropylene fibers (PPF) as 1%CF + 0.5% PPF and 0.5%CF + 1%PPF were prepared. Lastly, the mono polypropylene fibers as 1.5% PPF were used to reinforce the foamed concrete mix. These different mixes were tested, compressive strength, splitting tensile strength, flexural strength and flexural toughness tests. Besides, the heating procedure of the specimens was done by applying them to different burning degrees, which were 200, 250, 300, 350 and 400 °C. The results illustrated that the compressive and flexural tensile strengths of lightweight foamed concrete (LWFC) decreased with the increasing temperature. However, the highest effects on these strengths appeared once the temperature raised to 400 °C. The LWFC mix reinforced with polypropylene fiber exhibits more sensitive to elevated temperature than LWFC mixes reinforced with carbon fiber due to low melting point of polypropylene fiber.

Keywords Foamed concrete · Hybrid fibers · Toughness · Fire resistance

1 Introduction

Foamed concrete (FC) can be represented as one of the most developed materials in concrete technology that can widely be used in construction projects. Significant enhancements over the past 20 years in production equipment and better quality surfactants (foaming agents) has enabled the use of foamed concrete on a larger scale [1, 2]. The use of structural lightweight foamed concrete (SLWFC) which possesses good mechanical properties and durability ensures many benefits. Thus, SLWFC is a relatively new construction material which provides more efficient strength-to-weight ratio in structural elements. Concrete has inherently brittle nature and some disadvantages such as poor deformation and weak crack resistance in the practical usage. The fibers are used for overcoming the brittleness of lightweight foamed concrete [3]. The hybridization of different fibers may offer potential advantages in improving concrete properties. Hybrid fibers can offer reinforcement at all ranges of strains. The combination of low and high modulus fibers can arrest cracks at the micro level as well as macro level. Most of the studies on LWFC have focused on its normal temperature properties only, and a very few of its thermal properties [4, 5]. Song and Yin [6] studied the hybridization of carbon fiber and steel fiber could enhance the concrete performance in macro-crack bridging and micro-crack delaying. Steel fibers (SF) and carbon fibers (CF) can significantly increase the compression toughness of concrete. The use of hybrid fiber in high strength lightweight aggregate concrete

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(HSLWAC) specimens show significant increase in splitting tensile strength and flexural strength compared with concrete specimens reinforced with 1% volume fraction of mono fiber. The percentage of increase in splitting tensile strength for hybrid fiber (0.75 SF + 0.25 CF) up to 433%, while the percentage of increase in flexural strength is about 65% compared with the plain specimens. Dawood and Hamad [7], have also studied the LWFC reinforced with hybrid fibers using different percentages of glass and polypropylene fibers. The authors have found that the use of "0.4% glass fiber + 0.6% polypropylene fiber" has shown the best performance of LWFC. The results show highest increment in mechanical properties among other hybrid fibers mixes. Such increments were 21.5%, 16.7% and 36% for the compressive, flexural strength and splitting tensile, respectively. In regular concrete, the loss of strength due to high temperature is influenced primarily by the type of cement and the type of aggregate. Lightweight foamed concrete has a very good fire resistance and it shows a better performance than normal weight concrete at higher temperatures. On the first step of heating, the LWFC starting lost the absorbed, evaporable (free) water and then the chemically bound water. This loss of water would induce micro cracking that causing some reduction in strength of LWFC.

The reduction in compressive strength of LWFC between 20 and 150 °C corresponds to a decrease of the cohesion of the Van der Waal forces between the calcium silicate hydrate layers and leads to the formation of saline groups (Si–OH: OH–Si) that offers weaker bonding strength [8, 9].

Mydin and Wang [5] have also studied the mechanical properties of LWFC Subjected to elevated temperatures up to 600°C. The strength of LWFC was slightly reduced at 200 °C and the compressive strength of the samples still retained about 94% of the original value. At a stage of heating 200 °C to 400 °C, decomposition of C-S-H gel and the sulfoaluminate phases caused cracks in the specimens that cause significant effects on the strength of LWFC. When the temperature reaches to 400 °C, the residual strength of LWFC only about 75% of its initial value. When temperature up to 600 °C, the LWFC retained only about 40% of the original strength. The high air content in lightweight foamed concrete makes it suitable for use as firewalls.

Carbon fibers can improve the performance of the lightweight concrete at elevated temperature as shown in Plate 1. It can be seen clearly, that the carbon fibers existed after the temperature reached to 800 °C [9].

However, it can be concluded that there is still an obvious lack in the researches related to the use of LWFC reinforced with carbon or hybrid fibers. Also, the few studies related to the thermal properties of LWFC encourage the researchers to consider more studies covering such area. Therefore, this study was prepared to use carbon fibers and combination of carbon and polypropylene fibers with foamed concrete. These different mixes were tested and evaluated due to the application of elevated temperatures on the specimens produced from such foamed concrete.

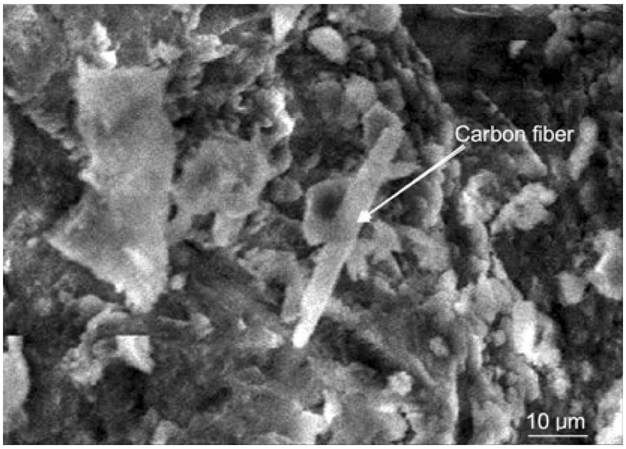

Plate.1 Scanning electron microscope image of the lightweight concrete with 1% mass fraction of carbon fibers after exposure to 800 °C [9]

Table 1 Physical properties of cements

Physical properties	Results	Limits of IQS: 5/1984
Initial setting time (minute)	100	≥ 45 min
Final setting time (minute)	320	≤ 600 min
Fineness (Blaine m^2/kg)	300	≥ 230 (m^2/kg)
Soundness by Autoclave Method (%)	0.02	Not more than 0.8
Compressive strength (MPa)		
3 days	21	≥ 15
7 day	27	≥ 23

2 Materials

The materials used in the present work are: cement, sand, water, silica fume, foam agent, carbon and polypropylene fibers.

Ordinary Portland cement (*OPC*) type (I) commercially known as AL-Mass cement factory (Al-Sulaimaniyahcity of Iraq) was used in this study. The physical characteristics of ordinary Portland cement are shown in Table 1 and it conforms to IQS: 5/1984 [10]. While, the chemical compositions of the cement have also conformed to IQS: 5/1984 and are shown in Table 2. *Silica fume* (*Sika Fume HR*) was used as a partial replacement of cement and its properties are presented in Table 3.

Table 2 Chemical composition of cement

Composition	Abbreviation	Percentage by weight	Limits of IQS: 5/1984
Lime	CaO	61	–
Silica	SiO_2	19.84	–
Alumina	Al_2O_3	5.08	–
Iron oxide	Fe_2O_3	4.8	–
Sulphate	SO_3	2.49	≤ 2.8
Potash	K_2O	0.1	
Soda	Na_2O	0.3	
Equivalent Na_2O	$Na_2O+0.658K_2O$	0.36	≤ 0.6%
Magnesia	MgO	2.48	≤ 5.0%
Loss on ignition	L.O.I.	3.8	≤ 4.0%
Insoluble residue	I.R.	0.40	≤ 1.5%
Main compounds (Bogue's equations)			
Tri calcium silicate	C_3S	49.45	–
Di calcium silicate	C_2S	19.57	–
Tri calcium aluminate	C_3A	5.34	–
Tetra calcium aluminate –ferrite	C_4AF	14.61	–

Table 3 Material properties of Silica fume

Form	Agglomerated
Particles color/appearance	Grey
Specific gravity	2.20
Size of particles	0.1 μ
Dosage	2–10% by weight of cement
Chloride content	Nil

Table 4 Grading of fine aggregate

Sieve no. (mm)	Passing (%)	Limits of ASTM C 33-02
# No.4 (4.75)	95	95–100
# No.8 (2.36)	80	80–100
# No.16 (1.18)	59	50–85
# No.30 (0.6)	44	25–60
# No.50 (0.3)	18	5–30
# No.100 (0.15)	4	0–10

The *natural sand* supplied from AL-Ukhaider region was used as fine aggregate. The specific gravity and fineness modulus of sand are 2.65 and 3, respectively. The grading limits are according to ASTM C 33-02 [11] as given in Table 4.

SikaLightcrete 02 was used as a foaming agent to obtain lightweight foamed concrete by entraining a controlled amount of air bubbles to concrete mix. The use of 30 parts of water for dilution of foaming agent was prepared before using it.

Foam was produced in a laboratory using locally manufactured machine as shown in Plate 2. As the foam added to the mortar, they were blended in the mixer to get a homogeneous mixture, as shown in Plate 3.

Cut carbon fibers 8 mm were used in the lightweight foamed concrete. While, *Monofilament polypropylene fibers* (*Sika fiber*) were used in the lightweight foamed concrete mixes. The properties of the carbon and polypropylene fibers are listed in Table 5.

3 Mix proportions

The proportions of the foamed concrete mixes (C0–C6) were prepared using different volumetric fractions of fibers. However, the control or reference mix (C0) has been prepared to get the flowability range of 110 ± 5%. Besides, the foamed concrete reinforced with carbon fibers mixes were designated by the mixes C1–C3 due to the use of 0.5, 1.0 and 1.5% of carbon fibers, respectively. The flow value was tested for each mix proportion. Furthermore, the hybridization of carbon fibers (CF) and polypropylene fibers (PPF) were presented in the mixes C4–C5. Such hybridization were as 1.0% CF + 0.5% PPF and 0.5% CF + 1.0% PPF, respectively. Also, the flow values were recorded for these mixes. Lastly, the mix "C6" was prepared by the inclusion of

Plate 2 Foaming machine

Plate 3 Addition of foam to the mix

Table 5 Properties of fibers

Fiber properties	Quantity for carbon fiber	Quantity for polypropylene fiber
Fiber length	8 mm	12 mm
Diameter	7 ± 2 micron	18 micron
Aspect ratio	1140	670
Tensile strength	3.5 GPa	500 MPa
Young's Modulus	230 GPa	3.5 GPa
density	1.7 g/cm^3	0.9 g/cm^3
Chemical Resistance	High	High
Absorption	Nil	Nil
Melt Point	3500 °C	160 °C
Shape	Chopped strand	Chopped strand

1.5% PPF in foamed concrete mix. The flowability was also measured for this mix. Table 6 shows the mix proportions of foamed concrete mixes reinforced with fibers. Whereas, Table 7 shows the weights of each proportion used in the control mix.

4 Experimental work

After 90 days curing at 20 ± 2 °C for all specimens, the molds of 100 mm cubes were used for testing the compressive strength of the foamed concrete mixes according to BS 1881: part 116 [12], and the average of three cubes was used to determine such strength for each temperature regime. Whereas, the cylindrical molds ϕ 100 × 200 mm were used for splitting tensile strength according to ASTM C 496 [13] and the average of three cylinders was used to determine such strength for each temperature regime. Three prisms of 40 × 40 × 160 mm were used to determine the flexural toughness for each temperature regime at age of 90 days. The flexural toughness test was carried out in accordance with ASTM C 1018 [14].

5 Burning regime

Firstly, the heating procedure of the specimens was done by applying them to different burning degrees, which were 200, 250, 300, 350 and 400 °C at age of 90 days by using electrical furnaces. Each temperature was maintained for 1.5 h to achieve the burning steady state, due to the heating rate of furnace by 10 °C/min. Secondly, the specimens were kept in the furnace for 24 h until the furnace cooled directly upon completing the burning cycle. Finally, the specimens were tested in compressive strength, splitting strength and flexural toughness. Figure 1 shows the scheme for the heating regime. Plate 4 shows the furnace

Table 6 Mix proportions of foamed concrete mixes reinforced with fibers

Mix type	Mix proportion					Carbon fiber %		Flow	Fresh density
	Cement	Sand	Water	Silica fume	Foam Kg/m^3	CF	PPF	%	kg/m^3
C0	0.9	1.9	0.38	0.1	1	–	–	110	1820
C1	0.9	1.9	0.35	0.1	1	0.5	–	80	1800
C2	0.9	1.9	0.37	0.1	1	1	–	75	1810
C3	0.9	1.9	0.41	0.1	1	1.5	–	60	1820
C4	0.9	1.9	0.38	0.1	1	1	0.5	80	1800
C5	0.9	1.9	0.37	0.1	1	0.5	1	80	1800
C6	0.9	1.9	0.37	0.1	1	–	1.5	90	1800

Table 7 Mix proportions of the control mix

Mix	Mix Proportion (cm:s)	w/cm	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Silica fume (kg/m^3)	Foam agent (kg/m^3)	Voids (%)
C0	(1:1.9)	0.34	485	1024	184	54	1	17

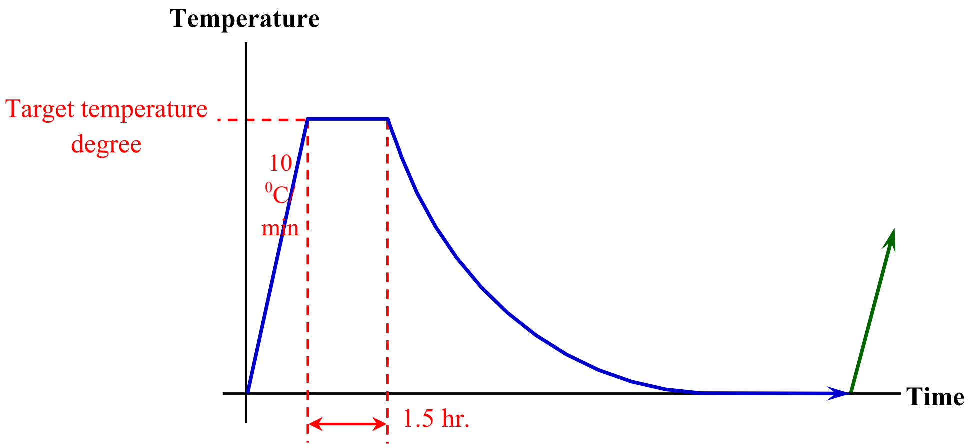

Fig. 1 Scheme for the heating regime

Plate 4 Furnace used in the heating regime

used in such regime and the specimens exposed to different temperatures.

6 Results and discussion

6.1 Compressive strength

The results of residual compressive strengths for specimens after the exposure to different stages of temperature degrees are shown in Table 8.

Generally, the compressive strength of LWFC decreases with the higher temperatures. Within 200 °C, the changes of residual compressive strength values were slightly reduced with the temperature for all mixes. The decrease in compressive strength between 20 and 200 °C corresponds to a reduction of the cohesion of the Van der Waal forces between the calcium silicate hydrate layers. This decreases the surface energy of calcium silicate hydrate and leads to

Table 8 Residual compressive strengths for different temperature degrees

Mixes	Compressive strength (MPa) at age 90 days					
	20 °C	200 °C	250 °C	300 °C	350 °C	400 °C
C0	18.4	18.4	17.0	16.5	15.9	15.7
C1	19.6	19.4	18.9	18.4	17.7	17.1
C2	24.7	23.9	23.4	22.4	21.9	21.7
C3	23.8	23.3	22.7	22.5	21.9	21.4
C4	15.4	15.1	14.5	13.7	13.1	12.3
C5	22.7	22.1	21.5	20.8	20.1	19.0
C6	23.1	22.4	21.8	21.1	20.5	20.1

the formation of silanol groups (Si–OH: OH–Si) that presents weaker bonding strength [8]. However, because this change only affects the concrete superficially, the reduction in concrete strength is not significant and the compressive strength of the foamed concrete mixes at 200 °C still retained about 97% of the original unheated value. However, when the temperature ranged between 200 to 400 °C, decomposition of C-S-H gel and the sulfoaluminate phases caused cracks in the specimens. These cracks had significant effects on the compressive strength of foamed concrete [15].

When the temperature reached to 400 °C, the reference mix of LWFC (C0) decreased strength by about 15% compared with the original strength at 20 °C. While, the LWFC reinforced with carbon fiber, the incorporation of 1.5% of carbon fibers exhibits the highest relative residual strength that is 90% of original strength at 20 °C. This is because the carbon fibers have high elastic modulus and high melting point. Therefore, carbon fibers bridge and resist cracking in the concrete, and can control the volume change of concrete due to rapid change of temperature and then mitigate the initiation and expansion of inner micro-defects of concrete [15, 16].

For LWFC reinforced with polypropylene fiber, the residual compressive strength at 400 °C was 80% of original compressive strength at 20 °C. This is the lowest relative residual strength obtained in this study. This can be related to the melting and vaporizing of polypropylene fiber that caused a weakness in concrete matrix [17]. For LWFC with hybrid fibers, the residual strengths at 400 °C were about 84% and 87% of original strength for 0.5% CF + 1% PPF (C5) and 1% CF + 0.5% PPF (C6), respectively. These results also indicate that Polypropylene fibers melt and vaporize due to the low melting point of such fibers, which induce micro-channel in the concrete [18].

6.2 Flexural strength

The results of residual flexural strengths for specimens after the exposure to different stages of temperature degrees are shown in Table 9.

Generally, the results of flexural strength are consistent with changes in the aforementioned other mechanical properties of LWFC. The flexural strength of all mixes reduced with the increasing of the temperatures. Once temperatures reached to 200 °C, calcium oxide was formed due to the dehydration of calcium hydroxide $Ca(OH)_2$. Then, initial micro cracks is created as the chemically bound water molecules were scattered to the capillary pores. These micro-cracks were expanded adjacent the un-hydrated cement particles and led to a reduction in flexural strength of concrete as it is negatively influenced by cracks [19–21]. For reference LWFC (C0), the residual flexural strength at 200 °C was 96% of the original strength at 20 °C and at 400 °C was 59% of the original strength at 20 °C.

For LWFC reinforced with carbon fiber, the residual flexural strength at 200 °C for 1.5% carbon fiber (C3) was 78%

Table 9 Residual flexural strength for different temperature degrees

Mixes	Flexural strength (MPa) at age 90 days					
	20 °C	200 °C	250 °C	300 °C	350 °C	400 °C
C0	5.1	4.9	4.6	4.5	3.2	3.0
C1	6.2	5.2	5.0	4.8	4.0	3.8
C2	6.9	5.5	5.1	5.0	4.7	4.3
C3	7.6	5.9	5.3	5.2	5.1	4.8
C4	6.8	4.8	4.3	4.2	3.1	2.8
C5	7.0	5.5	4.7	4.8	4.0	3.7
C6	7.4	5.7	5.0	4.9	4.5	4.2

Table 10 Average flexural toughness indices for prism 40 × 40 × 160 mm, using ASTM C 1018

Mixes	Indices											
	20 °C		200 °C		250 °C		300 °C		350 °C		400 °C	
	I_5	I_{10}	I_5	I_{10}	I_5	I_{10}	I_5	I_{10}	I_5	I_{10}	I_5	I_{10}
C0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
C1	2.2	2.2	2.3	2.3	2.2	2.2	2.1	2.1	1.8	1.8	2.0	2.0
C2	3.3	3.7	3.0	3.7	2.5	2.5	2.2	2.3	2.3	2.4	2.4	2.4
C3	3.8	4.1	3.3	3.8	2.9	3.1	2.8	3.5	2.6	2.8	2.5	2.7
C4	3.7	4.6	1.8	1.8	1.5	1.5	1.3	1.3	1.0	1.0	1.0	1.0
C5	3.4	4.3	3.1	4.6	2.2	2.2	2.2	2.2	1.9	1.9	1.7	1.7
C6	3.3	4.1	2.9	3.9	2.3	2.3	2.2	2.4	2.5	2.6	2.1	2.5

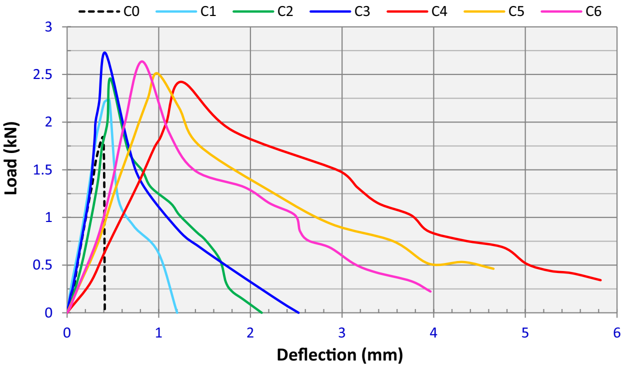

Fig. 2 Load-deflection curve for LWFC at normal temperature degree (20 °C)

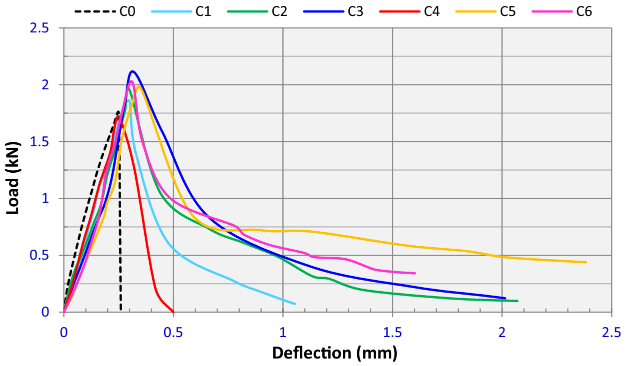

Fig. 3 Load-deflection curve for LWFC after exposure to 200 °C

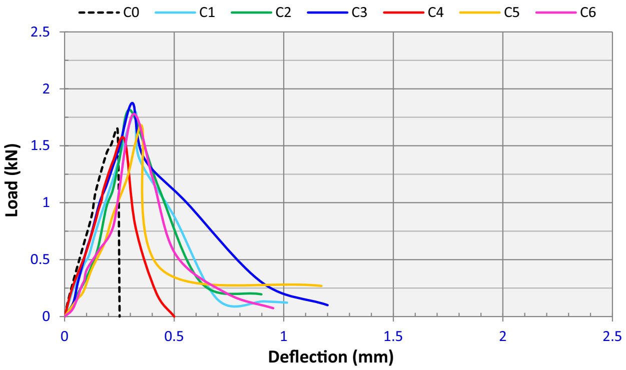

Fig. 4 Load-deflection curve for LWFC after exposure to 250 °C

of the original strength at 20 °C. Whereas at 400 °C, the residual splitting tensile strength for such mix was 63% of the original strength at 20 °C.

On the other hand, for the LWFC reinforced with polypropylene fiber, the result of residual flexural strength at 200 °C for 1.5% polypropylene fiber (C4) was 71% of the original strength at 20 °C. At 400 °C, the residual splitting tensile strength for such mix was 41% of the original strength at 20 °C.

For LWFC reinforced with hybrid fibers, the residual flexural strengths at 400 °C were 53% and 57% of original strength for 0.5% CF + 1% PPF (C5) and 1% CF + 0.5% PPF (C6), respectively. Again, this behavior also related to same causes mentioned in the previous section.

6.3 Flexural toughness

The results of flexural toughness by using 40 × 40 × 160 mm prisms in three-point bending test at normal temperature and after exposing to elevated temperatures are shown in Table 10. The load–deflection curves for all mixes at normal temperature and after the exposure to high temperatures are shown in Figs. 2, 3, 4, 5, 6 and 7.

Flexural toughness of concrete is adversely influenced by cracks either on a macro or on micro scale, which are caused by high temperatures [19, 20].

However, it can be seen that the flexural toughness of all mixes decreased clearly with the increasing of the temperatures. For LWFC mixes reinforced with carbon fiber, the results of toughness indices (I_5 and I_{10}) were slightly decreased with increasing of temperature degrees, the toughness indices I5 and I10 for 1.5% carbon fiber (C3)

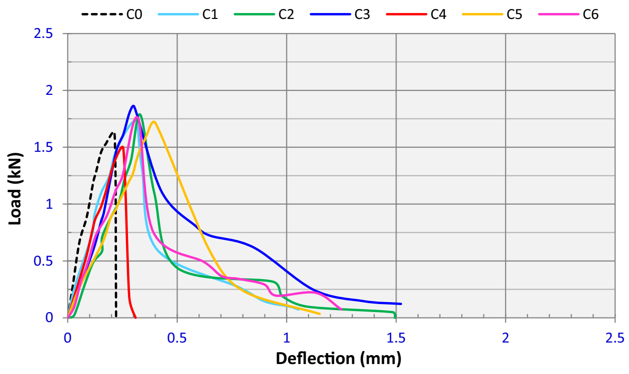

Fig. 5 Load-deflection curve for LWFC after exposure to 300 °C

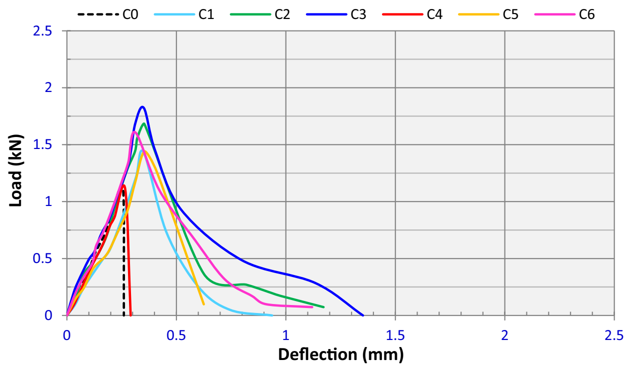

Fig. 6 Load-deflection curve for LWFC after exposure to 350 °C

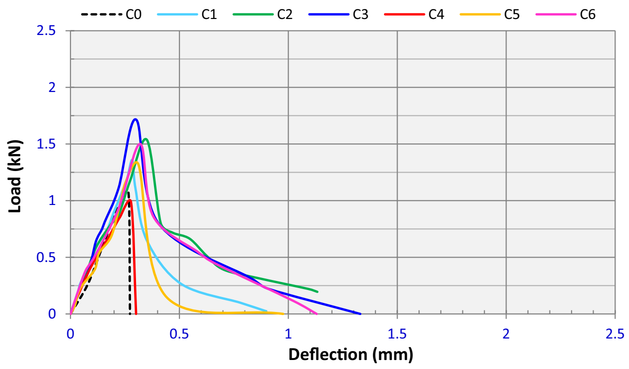

Fig. 7 Load-deflection curve for LWFC after exposure to 400 °C

were 3.3 and 4.1, respectively, at normal temperature degree. Whereas, the toughness indices I5 and I10 for such mix were 2.5 and 2.7, respectively, at 400 °C.

For LWFC mix reinforced with polypropylene fiber, the results of toughness indices (I_5 and I_{10}) were significantly dropped with the increasing of the temperatures, the toughness indices I5 and I10 for 1.5% polypropylene fiber (C4) were 3.7 and 4.6, respectively, at normal temperature degree. The toughness indices I5 and I10 for such mix were 1.8 for both indices at 200 °C. At temperature 350 °C, the toughness indices I5 and I10 were 1.0. This means, that the polypropylene fibers incorporated in LWFC were fully melted and vaporized.

On the other hand, the LWFC mixes reinforced with hybrid fibers exhibited superior flexural toughness compared to the mono fibers. The use of 1% CF + 0.5% PPF (C6) gave flexural toughness indices I_5 and I_{10} as 3.3 and 4.1, respectively, at normal temperature degree. Whereas, the toughness indices I5 and I10 for such mix were 2.1 and 2.5, respectively, at 400 °C. Again, this behavior also related to same causes mentioned in the previous section. This observation can be attributed to the fact that the carbon fibers which are stiffer than polypropylene in the hybrid fiber system provide reasonable first crack strength and ultimate strength. Whereas, polypropylene fibers are relatively flexible and lead to improve toughness and strain capacity in the post-crack zone [21, 22].

6.4 Splitting tensile strength

The results of residual splitting tensile strengths for specimens after the exposure to different stages of temperature degrees are shown in Table 11.

Generally, the tensile strength is relatively more sensitive to such cracks than that of compressive strength of LWFC [15, 16].

The reduction in the splitting tensile strength of LWFC occurred after 200 °C. This behavior is attributed to free water and chemically bound water in the LWFC mixes that evaporated from the porous body, generating micro cracks in the matrix [8]. For reference mix (C0), the residual splitting tensile strength at 200 °C was 90% of the original strength at 20 °C. After 250 °C, a significant drop in tensile strength was occurred.

At 400 °C, the splitting tensile strength was about 50% of the initial value. This is because the chemical constitution of LWFC started to break down due to decomposition of the C-S-H and sulfoaluminate phases [23].

For LWFC reinforced with carbon fiber, the residual splitting tensile strength at 200 °C for 1.5% carbon fiber (C3) was 91% of the original strength at 20 °C. Whereas, at 400 °C, the residual splitting tensile strength for such mix was 66% of the original strength at 20 °C, which is the highest value of relative strength at 400 °C. This is related to the ability of carbon fiber up to some high elevated temperatures to restrict the initiation and expansion of cracking in the concrete due to its tensile resistance, which maintained higher residual strengths of concretes after the exposure to high temperature [17–19, 24].

On the other hand, for the LWFC reinforced with polypropylene fiber exposed to high elevated temperatures,

Table 11 Residual splitting tensile strength for different temperature degrees

Mixes	Splitting tensile strength (MPa) at age 90 days					
	20 °C	200 °C	250 °C	300 °C	350 °C	400 °C
C0	2.0	1.8	1.6	1.2	1.2	1.0
C1	2.1	1.9	1.8	1.5	1.3	1.2
C2	2.8	2.5	2.5	2.1	1.9	1.7
C3	3.2	2.9	2.7	2.4	2.3	2.1
C4	2.2	1.7	1.6	1.5	1.2	1.0
C5	2.3	2.2	2.1	1.8	1.6	1.3
C6	3.1	2.9	2.5	2.3	2.0	1.9

the results exhibit worse influence on the splitting tensile strength than that of carbon fiber mixes. At 200 °C, the residual splitting tensile strength of 1.5% polypropylene fiber (C4) was 77% of the original strength at 20 °C. This is also related to the low melting point of polypropylene fiber. When 400 °C was reached, the residual splitting tensile strength was 45% of the original strength at 20 °C. For LWFC reinforced with hybrid fibers, the residual splitting tensile strengths at 400 °C were 57% and 61% of original strength for 0.5% CF + 1% PPF (C5) and 1% CF + 0.5% PPF (C6), respectively. This behavior also related to the property of polypropylene fibers to be melted and vaporized due to the low melting point. Whereas, the carbon fibers bridged and resisted cracking in the concrete, and enhanced the residual tensile strength of LWFC.

7 Conclusions

1. The flexural toughness of foamed concrete is enhanced with fibers, the use of carbon fibers exhibits more effect to bridge micro cracks. Whereas, the polypropylene fibers have a noticeable improvement on macro cracks.
2. The compressive strength of LWFC decreases with the increasing temperature. The changes of strength properties' values may be reduced slightly with the temperature up to 250 °C. However, the highest effects on compressive strength appeared once the temperature raised to 400 °C.
3. The flexural tensile strengths of LWFC decrease gradually with the increasing temperature. At 400 °C, the lowest residual strengths for both tests can be obtained with a control LWFC mix and for the LWFC reinforced with mono polypropylene fibers.
4. The LWFC mix reinforced with polypropylene fiber exhibits more sensitive to elevated temperature than LWFC mixes reinforced with carbon fiber due to low melting point of polypropylene fiber.
5. The flexural toughness of LWFC is enhanced with fibers, the use of carbon fibers exhibits more effect to bridge pre-crack zone. Whereas, the polypropylene fibers have a noticeable improvement in post-crack zone.
6. The toughness indices (I5 and I10) have decreased with increasing of temperature degrees for the LWFC reinforced with carbon fibers. Whereas, the toughness indices (I5 and I10) for the LWFC reinforced with polypropylene fibers are significantly dropped with the increasing of the temperatures. This means, that the polypropylene fibers are fully melted and vaporized after exposing to high elevated temperature.
7. The Splitting and flexural tensile strengths of LWFC decrease gradually with the increasing temperature. At 400 °C, the lowest residual strengths for both tests can be obtained with a control LWFC mix and for the LWFC reinforced with mono polypropylene fibers.

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Compliance with ethical standard

Conflict of interest The authors declare that they have no conflict of interest.

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