

Influence of Severe Hot-Dry Climate on the Mechanical Properties of Fibrous Reinforced Concrete Beams

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Abstract. This paper presents the results of the work carried out to study the influence of curing environment and steel fiber volume fraction on the flexural strength, flexural rigidity, flexural toughness, and ductility of fibrous reinforced concrete (RC) beams. A total of twenty simply supported beams were tested. Ten of the twenty beams were cured under controlled laboratory conditions and the other ten were cured under severe hot dry climate (SHDC) characterized by their intense heat, low relative humidity, direct solar radiation, and large diurnal variations of daily temperatures. Tests were carried out 28 and 90 days after casting.

Test results show that for non fibrous RC concrete beams the adverse effects of SHDC have more influence in reducing the flexural toughness than the flexural strength. On the other hand, test results indicate that under any of the two curing environment considered in this study, the flexural strength, flexural rigidity, flexural toughness and ductility of the fibrous RC beams are in direct proportion with the fiber content. Moreover, the results reveal that the enhancements in these engineering properties due to the steel fiber addition are not affected by the above described severe field conditions. Furthermore, inclusion of steel fibers in concrete helps, to some extent, in reducing the adverse effects of SHDC on the properties of concrete.

Introduction

Hot weather may increase the rate of initial hydration of the cement paste such that there will be not enough time for the hydration process to diffuse and precipitate throughout the interstitial space among the cement paste. Therefore, a high concentration of the hydration products is built up in the zone surrounding the hydrating cement grains and retard the

subsequent hydration [1]. The consequences of accelerating the rate of cement hydration may adversely affect the engineering characteristics of the concrete which include decreasing the 28-day and later strengths, increasing the tendency for drying shrinkage and differential thermal cracking, decreasing the durability, and increasing the permeability [2,3]. The aforesaid adverse effects of hot weather on concrete can, however, be reduced by proper curing.

Alsayed and Amjad [4] investigated the influence of hot-dry climate on the ultimate strength, shrinkage, porosity and permeability, and shrinkage of normal concrete slabs. It was concluded from the study that hot weather reduced the compressive strength by more than 25% of that cured under water. It was also concluded that with regard to the strength and durability, intermittent spraying of water twice a day with burlap covering was a suitable method of curing. In another study, Alsayed [5] studied the influence of hot-dry weather on the compressive strength of cubic and cylindrical specimens of high strength concrete. The study considered different curing regimes which include intermittent spraying of water with and without burlap covering, polythene sheet wrapping, chemical membrane brushing and air curing. Again, the results showed that intermittent spraying of water with burlap covering was an acceptable means to reduce the adverse effect of hot weather on the compressive strength of the concrete.

Austin *et al.* [6] simulated the heat and relative humidity of the arid climate to study the influence of 4 different curing methods on the strength and permeability of concrete blocks and beams. They deduced that among the different curing regimes considered in the study (burlap covering, polythene sheet wrapping, chemical membrane brushing, and air curing) wet burlap curing was the best curing method as far as the strength, water absorption and air permeability were concerned. The influence of the wind and the solar radiation were, however, not considered.

On the other hand, Kar and Pal [7] and Rangan and Shah [8, 9] investigated the influence of steel fiber addition on the modulus of rupture strength, ultimate compressive strain, and ductility of concrete. The investigators reported a substantial increase in the above properties due to the steel fibers addition. Shah and Rangan [9] extended the work to compare the improvement of ductility due to the addition of steel fibers with that of due to using steel compression or spiral conventional stirrups. It was observed that for identical volume of steel, stirrups and steel fibers significantly improve the ductility and increase the ultimate compressive strains.

Other investigators [10-12] studied the reinforcing effects of steel fibers when they were used in conjunction with bar reinforcement in structural members failing in flexure. They observed that fibers were effective in reducing deformation and increasing flexural stiffness, inhibiting crack growth and crack widening, improving the inelastic deformation, and ductility of the beams.

Now it has become clear that hot weather adversely affects the engineering properties of concrete and the intermittent spraying of water with burlap covering is an acceptable means of mitigating some of that adverse effects. It has also become clear that steel fiber addition to concrete with or without the presence of steel bars greatly improve the engineering properties of the concrete.

To the author's knowledge, however, there is not enough data whether the aforesaid benefits of adding steel fibers will hold if the reinforced concrete (RC) element is cured under hot dry climate. This may become of particular concern when the hot-dry weather is accompanied by low relative humidity, large diurnal variation in daily temperatures, and direct solar radiation (from here on will be referred to as severe hot-dry climate -SHDC) where the adverse effects of the hot-dry weather are highly aggravated.

The objectives of this study were twofold. Firstly, to study the influence of curing concrete under SHDC on the engineering properties of conventionally RC beams. Secondly, to investigate whether or not the addition of steel fibers has a pronounced impact on the engineering properties of the reinforced concrete beams cured under SHDC. To explore these tasks, a total of 20 beams with varying fiber contents were cast, subjected to either controlled laboratory or SHDC, and then tested 28 or 90 days after casting. The engineering properties of concrete monitored during the study include the load-deflection characteristics, ultimate flexural strength, flexural rigidity, moment-rotation relationship, flexural toughness, and ductility.

Experimental Program

Description of test specimens

A total of 20 beams were cast and tested. Ten of the twenty beams were cured outside under field conditions. The characteristics of the first three months of the field conditions are presented in Table 1. The other ten were laboratory cured (23 °C and 25% relative humidity). Curing process for specimens was chosen to replicate the actual practice in the field which consisted of spraying the specimens with water twice a day for seven days. The specimens were then left to dry under laboratory or field conditions until the time of testing (28 or 90 days after casting). Beams tested at the age of 28 days will be referred to as group A specimens whereas those tested at the age of 90 days will be referred to as group B specimens. All specimens were covered with burlap for the duration of the curing period. The total length of each flexural specimen was 2200 mm and the span of testing was 2000 mm. The beams had a cross section of 150×250 mm and were longitudinally reinforced by 3 ϕ 14 mm steel bars, provided reinforcement equal to the balanced steel reinforcement, at an effective depth of 223 mm and transversely by ϕ 6 mm stirrups at 100 mm center to center distance. Other specimen details are shown in Table 2 and Fig. 1.

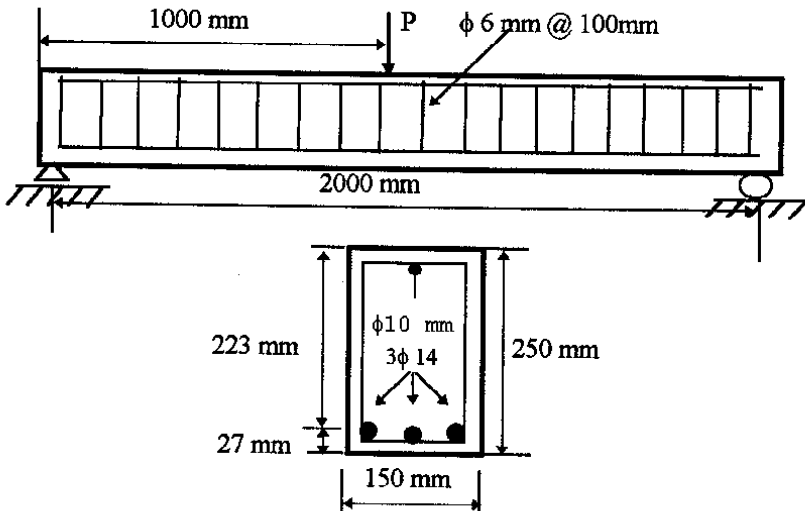
Table 1. Characteristics of the field conditions

Month	Min.temp. (Av.) °C	Max. temp. (Av.) °C	Relative hum. %	Wind speed m/sec.	Max. HSR* Cal./cm ²
June	28	42	25	2.85	79
July	30	42	26	5.25	77
August	29	42	29	3.10	77

* Maximum hourly solar radiation.

Table 2. Data of test specimens

Specimen designation	No. of specimens	Place of curing	Age at testing (days)	% Volume fraction of steel fibers, V_f
AL0.0	2	Lab	28	0.0
AF0.0	2	Field	28	0.0
AL0.5	2	Lab	28	0.5
AF0.5	2	Field	28	0.5
AL1.0	2	Lab	28	1.0
AF1.0	2	Field	28	1.0
BL0.0	2	Lab	90	0.0
BF0.0	2	Field	90	0.0
BL1.0	2	Lab	90	1.0
BF1.0	2	Field	90	1.0

**Fig. 1. Cross section and reinforcing details.**

Material properties

The cement used was of Type I Portland cement. The fine aggregates consisted of locally available natural desert sand with a fineness modulus of 3.3. The coarse aggregates consisted of crushed limestone from quarries around the city. The physical properties of the fine and coarse aggregates are listed in Table 3. The average 28-day compressive strength of the plain concrete was 20.64 MPa. The longitudinal reinforcement had a yield strength, f_y , of 553 MPa and the transverse reinforcement had a yield strength of 330 MPa. The fibers were two inch cold drawn crimped steel fibers with a tensile strength of 1240 MPa and an aspect ratio of 43. To reduce the amount of the water required to obtain a workable concrete, a sulphonated naphthalene superplasticizer conforming to ASTM C494 type F with a dosage of approximately 4.0 liters/m³ of concrete was used. The mixture proportions considered here are shown in Table 4. All mixes were identical except for the content of the steel fibers. Mix 1 was used to cast the beams containing no fibers. Mixes 2 and 3 were used to cast the beams containing, by volume, 0.5% and 1.0% fibers, respectively.

Table 3. Properties of coarse and fine aggregates

Property	Material	
	Coarse aggregate	Fine aggregate
Maximum size aggregate	10 (mm)	—
Fineness modulus	—	3.3
Unit weight (kg/m ³)	1520	1670
Absorption %	2.04	2.37
Specific gravity:		
a. Bulk oven- dry	2.54	2.51
b. Bulk saturated surface dry	2.60	2.57
c. Apparent	2.68	2.67

Table 4. Mix proportions

Material	Mix 1	Mix 2	Mix 3
Cement (kg/m ³)	400	400	400
Aggregate (kg/m ³)	1100	1100	1100
Sand (kg/m ³)	730	730	730
Water (l/m ³)	247	247	247
Admixture (ml/kg cement)	9.75	9.75	9.75
Fibers (kg/m ³)	0	39.25	78.5

Testing procedure

Beams for flexural tests were tested over a span of 2000 mm using center-point loading. Vertical deflections of the beam were measured using an electrical linear voltage displacement transducer (LVDT) at the center point. The voltage readings of the LVDT were recorded using an HP data acquisition system. The load was applied until the testing machine stopped due to excessive travel of the hydraulic piston, failure of the beam due to excessive spalling of concrete on the tension side of the beam or crushing of concrete on the compression side. These different causes to terminate the test are expected to influence the values of some engineering properties of the beam which depend on the last recorded test outputs. Ductility and total flexural toughness are examples of these properties.

Results and Discussions

Load-deflection curves

Figures 2 and 3 represent the load-central deflection curves developed for the test specimens. Each curve shown in the figures represents the average of two curves of identical beams cured under similar conditions.

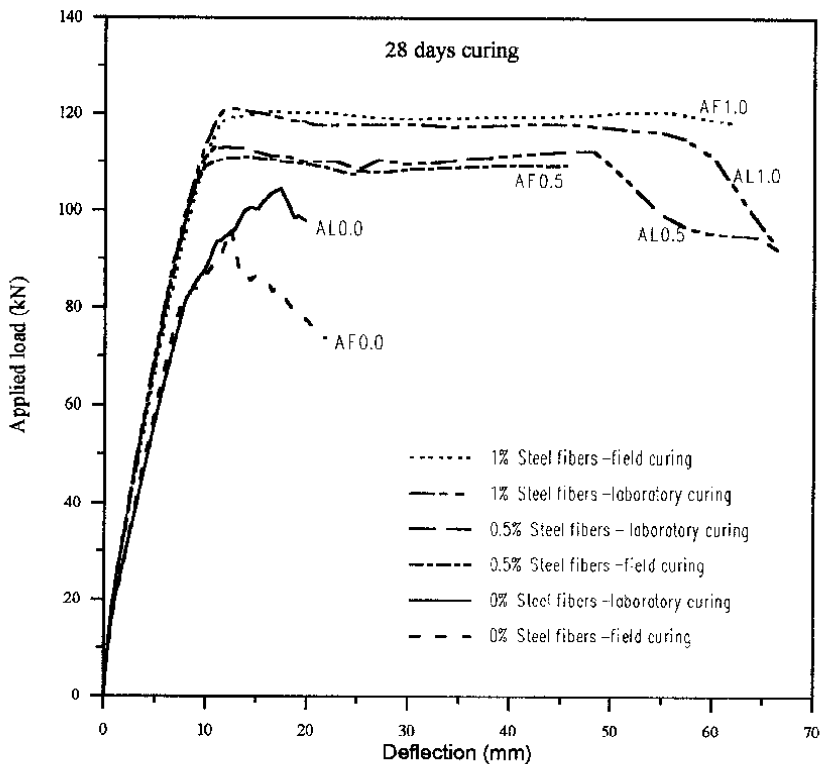


Fig. 2. Load-deflection relationship for beams subjected to laboratory or field curing for 28 days (Group A specimens).

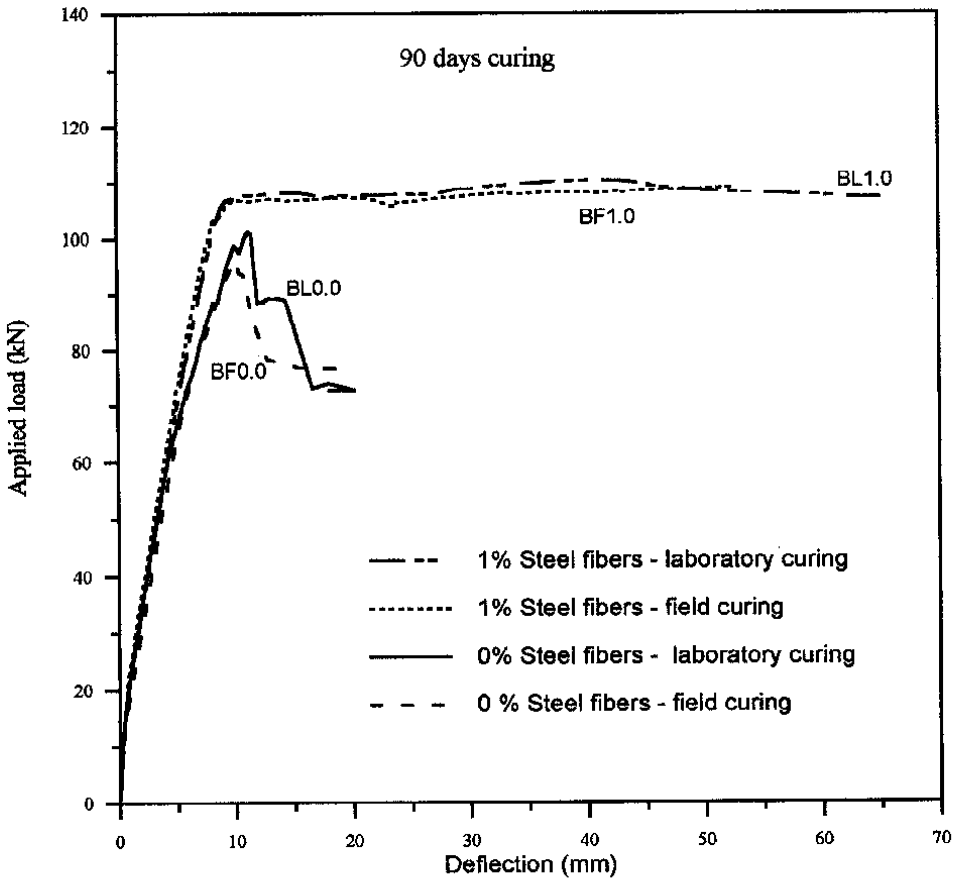


Fig. 3. Load-deflection relationship for beams subjected to laboratory or field curing for 90 days (Group B beams).

Results shown in Fig. 2 indicate that, SHDC has a modest influence on the load-deflection characteristics of non fibrous RC beams. The measured ultimate load for beams AL0.0 is only 8% higher than that of AF0.0 (see column 2 of Table 5). It seems, however, that the intermittent spraying of water is an effective way of reducing the adverse effects of SHDC. Adverse effects of harsh weather are, however, expected to be much higher for concrete elements with larger ratio of exposed surface area to volume [1], e.g. slab structures. Other factor that could have played some appreciable influence in reducing the harsh weather effects is the fact that the relative humidity inside the laboratory was almost the same as that of the field. Also, the temperature inside the laboratory, where all specimens in this study were prepared, and, in turn, the aggregate temperatures were 23 °C. Abbasi *et al.* [13] reported that the shear strength and moment capacity of RC beams that were prepared and cured in hot weather were reduced with increase in concrete mix temperature.

Table 5. Ductility and curvature ratios of flexural beams

Beams	Load at ultimate (kN)	Deflection at ultimate load (mm)	Maximum deflection (mm)	Ductility ratios	Maximum curvature (1/m)	Curvature ratios
(1)	(2)	(3)	(4)	(5)	(6)	(7)
AL0.0	104.4	17.3	19.8	1.1	0.051	1.00
AF0.0	96.2	12.3	21.8	1.8	0.081	1.59
AL0.5	113.5	11.0	66.4	6.0	0.845	16.57
AF0.5	111.0	13.70	45.5	3.3	0.839	16.50
AL1.0	121.2	12.25	66.1	5.40	1.144	22.43
AF1.0	121.5	12.25	62.12	5.07	1.070	20.98
BL0.0	101.35	11.21	20.21	1.60	0.029	0.57
BF0.0	94.32	10.00	20.01	1.58	0.250	4.90
BL1.0	110.4	13.00	65.0	5.0	0.363	7.12
BF1.0	109.2	10.40	59.3	5.7	0.301	5.90

Results presented in Fig. 2 also reveal that up to the first crack point (the point where the load-deflection curve deviates from straight line relationship) the load-deflection curves for the fibrous and non fibrous RC beams, are almost identical. Beyond the first crack point, the reinforced fibrous beams show a higher stiffness, indicating that fibers did not act before the formation of the matrix cracks. This supports the idea that fibers do not prevent the initiation of cracks, but they prevent their propagation and widening.

Furthermore, results presented in Table 5 and Fig. 2 demonstrate that the fiber content and the ultimate strength of the beam are directly related. The ultimate loads for beams AL0.0, AL0.5, and AL1.0 are 104.4, 113.5, and 121.2, respectively. Thus, due to the addition of 0.5% and 1% of crimped steel fibers, the ultimate load of the reinforced concrete beams increased by 9% and 16%, respectively. On the contrary, however, there is very little increase in the flexural stiffness when V_f increased from 0.5% to 1.0%. Previous tests [14, 15] reported that, at low fiber aspect ratio (l/d), which is the case in this study ($l/d=43$), the crimped fibers are less effective in improving the flexural stiffness and ultimate strength of concrete under flexural loads than the straight and hooked ones. Thus, further enhancement over that reported here should have been gained had fibers of straight or hooked shape and/or fibers with larger aspect ratio were utilized.

Results shown in Fig. 3 give emphasis on the observation made earlier that the adverse

effects of SHDC on beams cured by intermittent spraying of water, even after three months of field exposure, show only marginal influence on the load-deflection relationship of the non fibrous RC beams. The reduction in the ultimate load of beams BF0 due to the adverse effects of SHDC is about 7%. However, they were totally eliminated by adding 1% of steel fibers to the concrete mix. The difference in ultimate loads of beams BF1.0 and Beams BL1.0 became less than 1%.

It is interesting to note that, regardless of the curing environment or the exposure period considered here, beams with the same content of steel fibers show identical response to loading almost up to the failure point. This is an evidence that the benefit of adding steel fibers to the concrete mix of RC beams was not reduced when the adverse climatic conditions prevail.

Table 5 also lists the values of the ductility ratios for all beams tested in this study. The ductility ratio is defined here as the ratio of the maximum deflection achieved to the deflection at ultimate load. In comparison with the ductility of the non fibrous RC beams, the ductility of fibrous concrete beams tested 28 days after casting increased by 6 and 5.4 times as a result of adding 0.5 and 1% volume fraction of steel fibers, respectively. The results also indicate that, except for beams AF0.5, the gain in ductility as a result of steel fiber addition was not reduced by the adverse effects of SHDC. The reduction in the ductility ratio for beams AF0.5 may be ascribed, as explained earlier, to the influence of the different causes considered in terminating the test (see also Fig.2). Moreover, the gain in the ductility ratios for beams BL1.0 and BF1.0, tested 90 days after casting, were 5 and 5.7, respectively. Again the adverse effects of SHDC did not reduce the gain in ductility due to the steel fiber addition even after relatively long period of exposure.

It is worth noting here that, as a consequence of the improvement in the ductility of the reinforced concrete beams due to the addition of steel fibers, all beams containing steel fibers failed in flexure whereas beams with no fibers failed in shear (RC beams with no steel fibers were design to fail in shear). These results indicate that fiber addition has more influence on improving shear stresses than on flexural strength. Other investigators reported an increase, due to steel fiber addition, of 10% in flexural strength [11] and in the order of 40% in shear strength [16, 17]. Thus, addition of the steel fibers to the concrete mix altered the mode of failure for the non fibrous RC beams from shear type to flexural one.

Moment-curvature relationships

The average moment-curvature curves for laboratory and field cured specimens are shown in Figs. 4 and 5. The improvements in curvature values up to the termination points for all specimens as compared to that of the non fibrous RC beams cured inside the laboratory and tested 28 days after casting are shown in column 7 of Table 5.

As can be seen in Fig. 4 and Table 5 that the curvatures of the fibrous RC beams were greatly improved due to the fiber addition. As compared with the curvature of beams AL0.0,

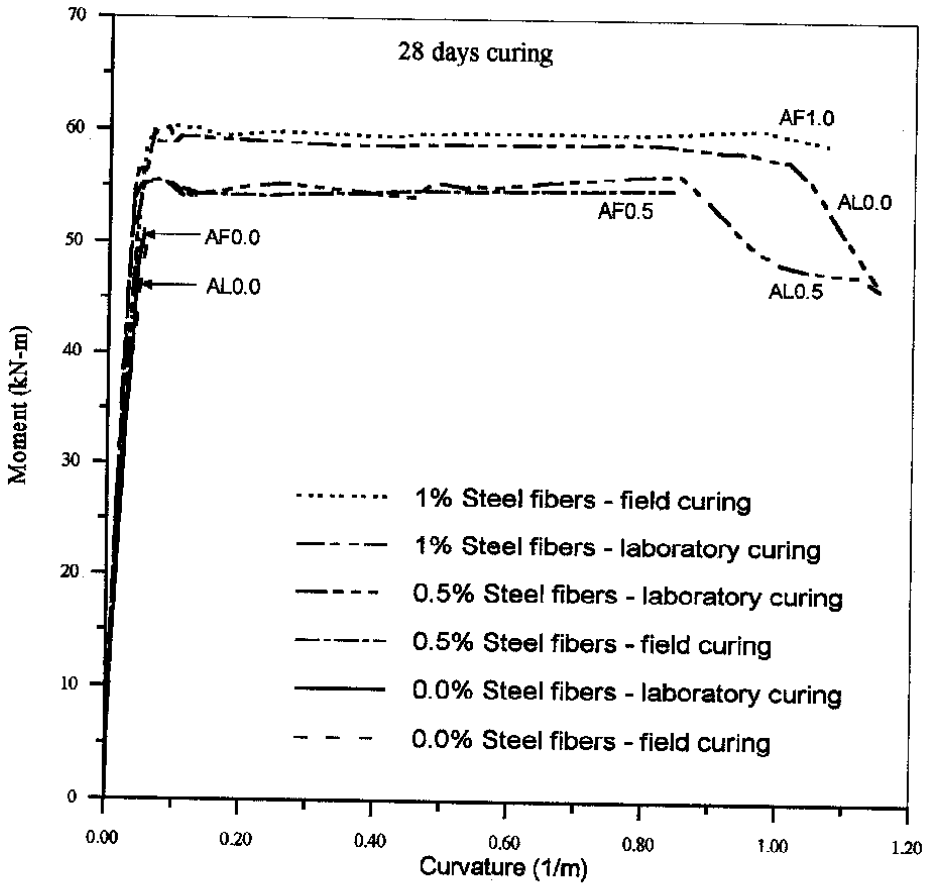


Fig. 4. Moments versus curvature for beams subjected to laboratory or field curing for 28 days (Group A specimens).

curvature of beams AI.0.5 and AL1.0 increased by 16.57 and 22.43 times, respectively. On the other hand, the corresponding increase in the curvature values of beams BL1.0 and BF1.0 are 5 and 5.7 times, respectively. Results presented in column 7 of Table 5 also indicate that prolonging the exposure period of the beams from 28 to 90 days reduced, relatively, their curvature capacity. Therefore, the curvature values of beams BL1.0 and BF1.0 are smaller than those of beams AL1.0 and AF1.0, respectively. However, the results also show that the curvature ratios for beams BL1.0 and BF1.0 are almost the same and were not reduced by SHDC. Again this may be regarded as another evidence that SHDC did not reduce the enhancement in engineering characteristics as a result of steel fiber addition.

Flexural toughness

Many tests have been developed to measure the flexural toughness of concrete beams

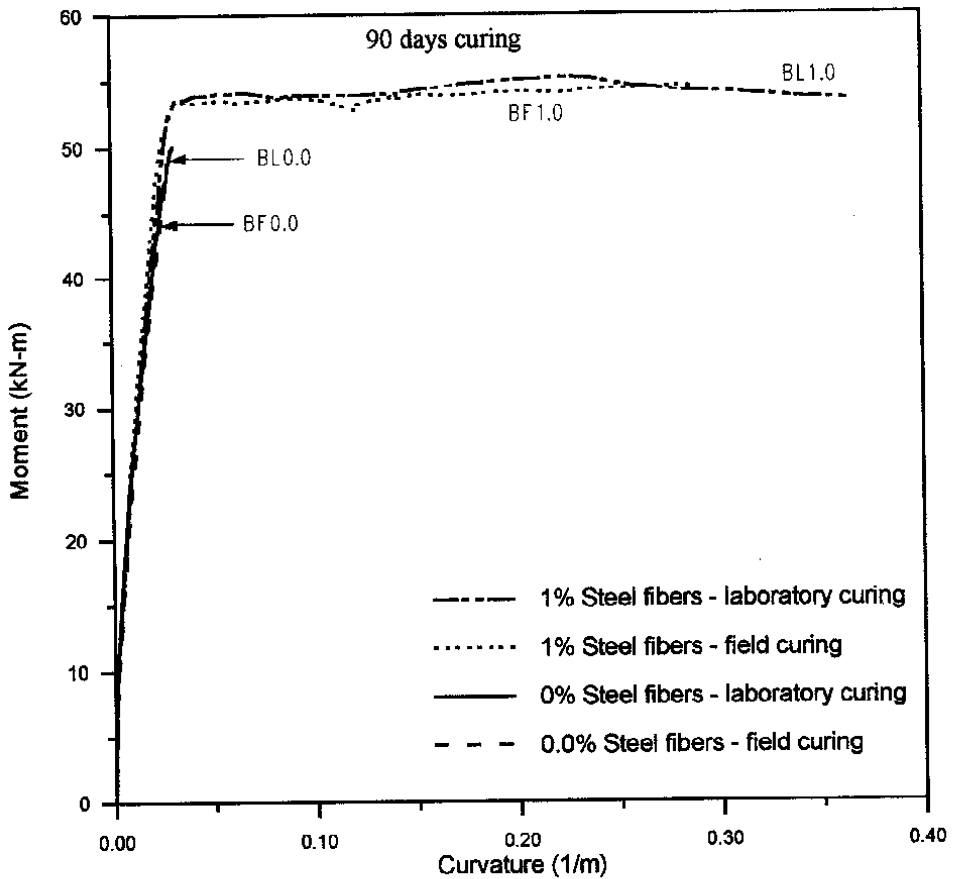


Fig. 5. Moments versus curvature for beams subjected to laboratory or field curing for 90 days (Group B specimens).

subjected to bending stresses. A summary of the various test characteristics for ten of the available methods is reported by Gopalaratnam and Gettu [18]. However, flexural toughness is usually defined as the area under the load-deflection curve observed during a bending test [19]. In this study, it is defined as the area under the load-deflection curve up to the deflection of 19.8 mm. The value of 19.8 mm was selected because it was reached by all test specimens. Table 6 shows the values of the flexural toughness up to the 19.8 mm and the total flexural toughness, which is the total area under the load-deflection curve up to the termination point of the test. The relationship between V_f and the computed values of flexural toughness for the beams in Group A are also shown schematically in Fig. 6.

It can be seen from Table 6 and Fig 6 that under any given curing conditions the flexural toughness and fiber content are directly related. Adding 0.5% and 1% of steel

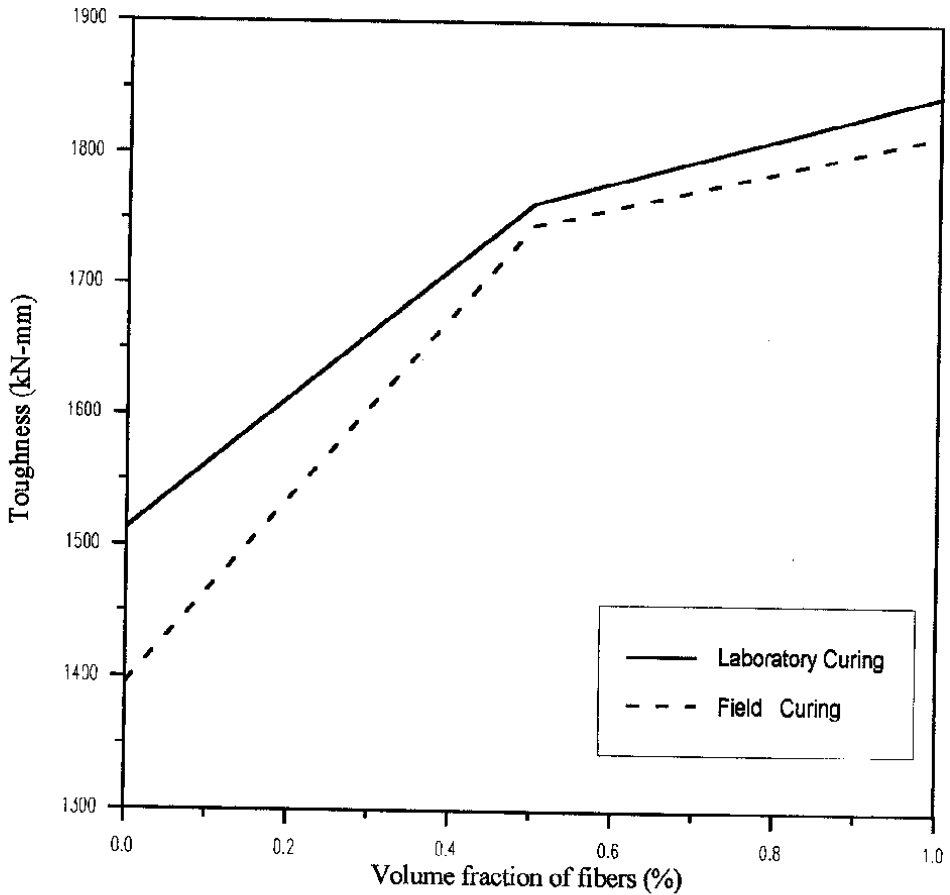


Fig. 6. Toughness versus volume fraction for group A beam after 28 days of laboratory and field exposure.

fibers increased the flexural toughness of beams AL0.5 and AL1.0 as compared with that for beams AL0.0 by 16.5 and 22%, respectively. The corresponding flexural toughness increase for beams BL1.0 and BF1.0 are 13.7 and 14.6%, respectively. Comparing the flexural toughness for beams AF0.0 and BF0.0 with that of beams AL0.0 reveals that the adverse effects of SHDC reduced the flexural toughness of beams AF0.0 and BF0.0 by 7.7% and 22%, respectively. The later value is higher than the corresponding reduction in the flexural strength for the same beams. Thus, the results indicate that SHDC has more adverse effects on the flexural toughness than on the flexural strength. This may be attributed to the fact that specimens cured in the field experienced higher shrinkage rate and quantity than their counterpart specimens cured inside the laboratory. However, the shrinkage was restrained at the reinforcing level, a process which probably induced microcracking in the vicinity of the reinforcing bars. This may lead to some reduction in the bond between the

reinforcing bars and concrete and, in turn, a more reduction in the flexural toughness than in flexural strength. As BF0.0 beams were exposed for a longer period of time to SHDC, they suffered further reduction in the bond between reinforcing bars and concrete and, in turn, had a higher reduction in flexural toughness than AF0.0 beams. In contrast, the flexural toughness of specimens AF0.5, AF1.0 and BF1.0. are about that of AL0.5, AL1.0, and BL1.0, respectively. This implies that SHDC did not influence the flexural toughness of the beams that were containing fibers. Once again, this result may also be considered as another evidence that fiber addition to concrete mixtures is an acceptable alternative in attempting to reduce the adverse effects of SHDC on RC beams.

Table 6. Summary of flexural toughness results

Group	Max def. (mm)	Area to 19.8 mm (kN-mm)	% change	Total toughness (kN-mm)
(1)	(2)	(3)	(4)	(5)
AL0.0	19.80	1513	-	1513
AF0.0	21.78	1396	-7.7	1545
AL0.5	66.40	1762	16.5	6723
AF0.5	45.48	1745	15.3	4540
AL1.0	66.06	1846	22.0	7174
AF1.0	62.12	1816	20.0	6890
BL0.0	20.21	1285	-15.05	1285
BF0.0	20.01	1181	-21.93	1181
BL1.0	64.98	1721	13.7	6634
BF1.0	59.34	1734	14.6	5976

Furthermore, the total flexural toughness values shown in column 5 of Table 6 substantiate the results presented earlier about the great benefit of adding steel fiber for beams subjected to SHDC. However, for the same reasons discussed earlier, as the total flexural toughness is directly influenced by the termination point of the test, its values as listed in Table 6 can not be used to arrive at some definite conclusion about the interaction between the total flexural toughness and the adverse effects of SHDC

Conclusions

Based on the experimental results obtained in this study, the following conclusions may be drawn.

1. Addition of steel fibers increases the 28- and 90-day flexural strength, flexural rigidity, ductility, and curvature of beams.
2. The intense heat, low relative humidity, direct solar radiation, and large fluctuations in daily temperatures (severe hot dry climate- SHDC) have little influence on the 28 and 90-day flexural rigidity and flexural strength of the non fibrous RC beams cured with burlap covering and intermittent spraying of water.
3. Addition of 0.5 and 1% of steel fibers increases the ductility of the reinforced concrete beams by 6 and 5.5 times as compared with that of their counterpart non fibrous RC beams, respectively. The corresponding increase in curvatures are 16 and 22 times, respectively. The enhancements in the ductility and curvature are not reduced by the adverse effects of SHDC.
4. For non fibrous RC beams the adverse effects of SHDC reduce the flexural toughness for beams tested 28 and 90 days after casting by 8% and 22%, respectively. However, addition of 0.5 and 1% of steel fibers increases the flexural toughness, respectively, by 16.5 and 22% and these gains in flexural toughness values are not reduced by the adverse effects of SHDC.
5. Addition of fibers highly increases the shear capacity of beams. It alters the mode of failure from shear to flexural failure.

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أثر الطقس الجاف والحار على الخواص الميكانيكية للعوارض الخرسانية المسلحة بالألياف والقضبان المعدنية

صالح حامد السيد

قسم الهندسة المدنية، جامعة الملك سعود، ص. ب. ٨٠٠،

الرياض ١١٤٢١، المملكة العربية السعودية

(أستلم في ١١/١٢/١٩٩٦م؛ وقبل للنشر في ٢٢/٦/١٩٩٧م)

ملخص البحث. تعرض هذه الورقة نتائج الدراسة التي تم إجراؤها لمعرفة أثر ظروف المعالجة وحجم الألياف المعدنية على قوة وصلابة الانحناء، الطاقة اللازمة لكسر العينة، واللدونة للعوارض الخرسانية المسلحة بالقضبان والألياف المعدنية. ولقد تم اختبار ما مجموعه ٢٠ عارضة بسيطة، عشر منها عولجت في ظروف معملية متحكم فيها والعشر الأخرى عولجت تحت ظروف جوية جافة وحارة ذات حرارة عالية، درجة رطوبة منخفضة، أشعة شمسية مباشرة ومعدل عال في تغير درجة الحرارة اليومية. وتم إجراء الاختبارات بعد ٢٨ و ٩٠ يوماً من صبها.

وقد بينت نتائج الدراسة أنه بالنسبة للعوارض التي لا تحتوي على ألياف معدنية فإن التأثير السلبي للطقس الخارجي المتقدم وصفه على الطاقة اللازمة لكسر العينة أكبر من تأثيره على قوة الانحناء. وفي المقابل بينت النتائج أنه وتحت تأثير أي من الظروف الجوية المعتبرين في هذه الدراسة فإن قوة ومتانة الانحناء والطاقة اللازمة لكسر العينة واللدونة أيضاً مرتبطة ارتباطاً طردياً مع حجم الألياف المستعملة. كما بينت الدراسة أن التحسن في الخواص الهندسية للعوارض نتيجة إضافة الألياف المعدنية لا تتأثر بالظروف البيئية القاسية المذكورة سابقاً بالإضافة إلى ذلك فإن نتائج الدراسة بينت أن إضافة الألياف المعدنية خففت من الأثر السلبي للطقس الحار والجاف الذي تعرضت له العوارض.