Journal of Ferdowsi Civil Engineering, Vol.31, No.3, 2018.

The Effect of Steel Fibers on Flexural Cracking of Fiber in Reinforced Concrete Beams with Lap-spliced Bars

Arash Karimipour[1] M. Reza Esfahani[2*]

1. Introduction

Concrete carries flaw and micro-cracks both in the material and at the interface. These defects can be favorably modified by adding short, randomly distributed fibers of various suitable materials. Fibers not only suppress the formation of cracks but also control their propagation and growth. When combined with post-crack bridging capability of fibers in restrained concrete, fibers reduce crack widths and cracks areas. Steel and synthetic fibers are used to enhance fibers interaction with the matrix at the level of micro-cracks and effectively bridge these cracks and delay their unstable growth in the hardened state when fibers are properly bonded. Once the maximum tensile capacity of the composite is achieved, and coalescence and the conversion of micro-cracks to macro-cracks have occurred, fibers continue to restrain crack opening and crack growth by effectively bridging across macro-cracks, depending on their length and bonding characteristics. A number of parameters affect the lap-spliced bars. According to Esfahani and Kianoush (2005), the lap-spliced length in spliced reinforced concrete beams is calculated using Eq.1 as follows:

$$l_d = \frac{T}{a\sqrt{f'_c}} = \frac{A_b f_y}{a\sqrt{f'_c}} \qquad (1)$$

where $\mathrm{a} = 7.2\mathrm{d_b}\frac{\frac{\mathrm{c}}{\mathrm{d_b}}+0.5}{\frac{\mathrm{c}}{\mathrm{d_b}}+3.6}$, A_b is the cross-sectional area of one longitudinal tensile bar in mm^2, $\mathrm{d_b}$ is the tensile bar diameter in mm and c is the minimum concrete cover. Eq. 1 is valid to calculate the lap-spliced bars only if an appropriate amount of transverse reinforcement is used over the lap-spliced bars. According to Esfahani and Kianoush (2005), this amount of transverse reinforcement is necessary to meet the ductility requirement of flexural beams. This paper presents the effect of steel fibers in reinforced concrete beams with lap-spliced bars on concrete cracking under static and cyclic loadings.

2. Properties of specimens

Ten specimens of laboratory beam with the section with the width of 150mm, height of 200mm and length of 2300mm and with different splice lengths of tension rebars and different percentages of steel fibers were manufactured and tested. Four specimens were subjected to static loads and six specimens were subjected to loading/unloading cycles. Among the specimens, one was selected as the control specimen without having lap-spliced bars and steel fibers. Other nine specimens were made using steel fibers with different volumetric percentages of 0, 1 and 2. The specimens were conducted under four-point bending tests. The details of specimens are presented in Fig. 1 and Table 1.

Table 1. Lap-spliced bars, the percentage of steel fiber and loading condition

Specimen	Steel fiber (%)	Lap-spliced bars
$\mathrm{W/o - St - 0\%}$	0	$-$
$\mathrm{l_d - Cyc - 0\%}$	0	l_d
$\mathrm{l_d - Cyc - 1\%}$	1	l_d
$\mathrm{l_d - Cyc - 2\%}$	2	l_d
$\mathrm{0.8l_d - St - 0\%}$	0	$0.8l_d$
$\mathrm{0.8l_d - St - 1\%}$	1	$0.8l_d$
$\mathrm{0.8l_d - St - 2\%}$	2	$0.8l_d$
$\mathrm{0.8l_d - Cyc - 0\%}$	0	$0.8l_d$
$\mathrm{0.8l_d - Cyc - 1\%}$	1	$0.8l_d$
$\mathrm{0.8l_d - Cyc - 2\%}$	2	$0.8l_d$

In Table 1, l_d is the calculated lap-spliced bars using Eq. 1. i% is the percentage of steel fibers. St and Cyc are the static and loading/unloading cycles, respectively. The tension lap-spliced bars $\mathrm{l_d}$ was 430 mm. In some specimens, the lap-spliced length of bars was reduced to $0.8l_d$ equal to 340mm. The stirrups spacing over the lap-spliced length were 30mm and over the rest of the beam length were 60mm.

3. Test Results

The maximum crack widths in the specimens are presented in Tables 2 and 3 in the specimens under static and loading/unloading cycles, respectively.
The load-displacement relationship of the specimens is presented in Figs. 2 and 3.

Table 2 The maximum crack width in specimens under static loading

Maximum crack widths (mm)	Specimen
1.30	$\mathrm{W/o - St - 0\%}$
1.70	$\mathrm{0.8l_d - St - 0\%}$
0.35	$\mathrm{0.8l_d - St - 1\%}$
0.25	$\mathrm{0.8l_d - St - 2\%}$

4. Conclusions:

In this research, the effect of steel fibers on flexural cracking of fiber reinforced concrete beams with lap-spliced bars under static and loading/unloading cycles was investigated. It was shown that significant

---

Arash karimipour. Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.
Corresponding author:M. Reza Esfahani. Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran. E-mail: esfahani@um.ac.ir.

increase in the volume of steel fibers results in reducing the flexural crack width in beams . Steel fibers in specimens subjected to static loading and loading/unloading cycles increased the energy dissipation.

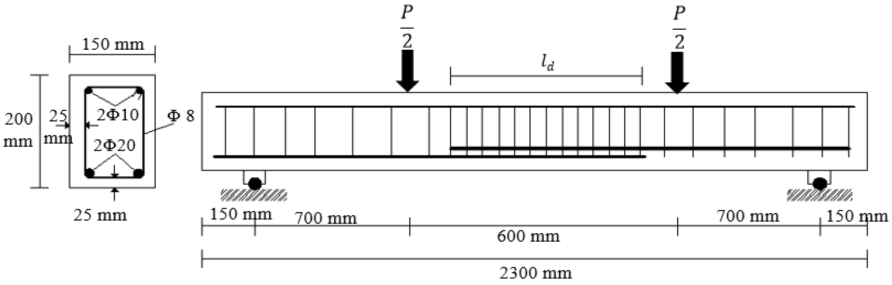

Fig 1. Geometry of the beams and the arrangement of reinforcement

Table 3 The maximum crack width in specimens under loading/unloading cycles

The load at first cracking (Ton)	Maximum crack widths (mm)				Specimens
	Fourth cycle	Third cycle	Second cycle	First cycle	
1.00	4.00	2.10	0.45	0.20	$0.8l_d - Cyc - 0\%$
2.00	1.20	0.60	0.25	0.10	$0.8l_d - Cyc - 1\%$
3.00	0.65	0.30	0.15	0.05	$0.8l_d - Cyc - 2\%$
1.50	3.00	1.80	0.35	0.05	$l_d - Cyc - 0\%$
2.00	0.70	0.55	0.20	0.01	$l_d - Cyc - 1\%$
4.00	0.50	0.25	0.10	0.00	$l_d - Cyc - 2\%$

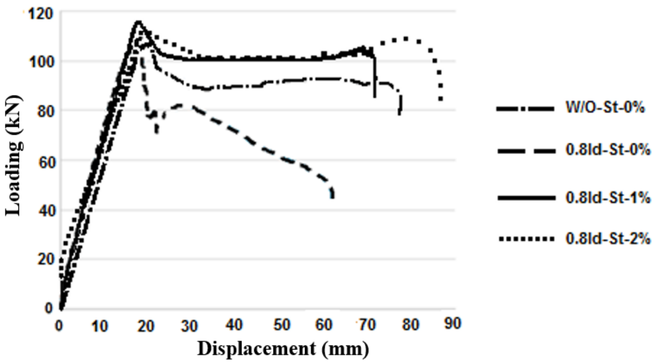

Fig 2. The load-displacement relationship under static loading

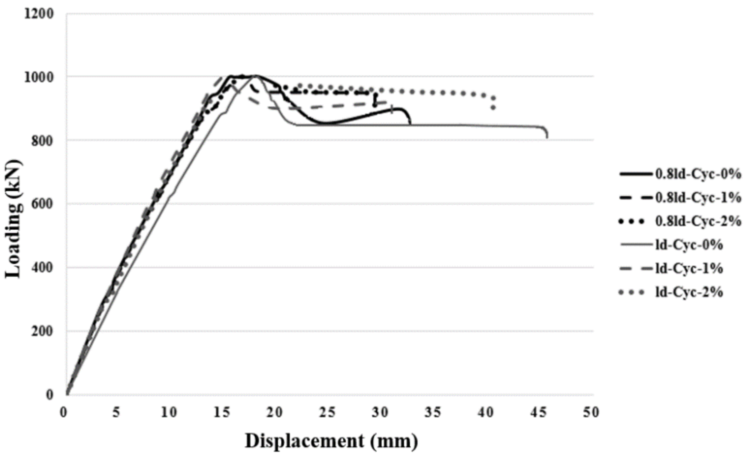

Fig 3. The load-displacement envelopes under loading/unloading cycles