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The Flexural Ductility Behavior of Reinforced Concrete Beams with Tension Lap Splices Exposed to Fire

Masood M.M. Irheem*, Omar A. El-Nawawy

Department of Structural Engineering, Ain Shams University, Cairo, Egypt

Hatem H. Gheith

Housing & Building National Research Center, Giza, Egypt

Ayman S. Abo-Beah

Department of Structural Engineering, Ain Shams University, Cairo, Egypt

*Email: masoud.e@hotmail.com

ABSTRACT: Based on a comprehensive review of both previous studies and implemented practices in the field of construction structures, it's obvious that reinforcing steel bar's length is limited. Consequently, lap-splices are commonly used in reinforced concrete (RC) structures to solve such problem. Generally, in the design process, safety and serviceability must be satisfied. In essence, in beams with lap splices it's important to check the ductility, since some variables as fire of RC beams can change the behavior. The present paper aims to validate the effect of fire on the flexural ductility behavior of reinforced concrete beam with lap splice. An experimental test Program of thirteen simply supported RC beams with lap-splices were designed, cast and tested in laboratory. The main selected variables are: concrete cover, temperature and fire exposure duration. Results show that; under fire effect with different concrete cover, duration and temperature over the lap-splices zone has major effects on the ductility of RC beams. As, the ductility of beams decreases when the temperature and fire duration increases. Furthermore, ductility of RC beams increases as concrete cover increases under similar conditions. Collectively, this study shows that the fire has a major effect on the bond strength of lap-spliced RC beams and ductility has different behavior when compared with non-fired beam. Consequently, codes have to take fire effects on the lap-splice in design process.

KEYWORDS: Lap-splices, bond strength, fire duration, RC beam, ductility, Temperature.

1 INTRODUCTION

One of the main problems of reinforced concrete (RC) structures is the bond between concrete and tension reinforced bars. In particular, safety and strength [1], where the bond strength has a major effect on the behavior of RC beams with lap splices. As addressed in ACI318-14[2] & EC 203[3], many factors affect the bond strength between concrete and reinforced bars. This includes; diameter of bar, concrete compressive strength, spacing between reinforced bar, development length, type of bar surface condition, splice end shape, the amount of transverse reinforcement over the splice region, loading conditions and the surrounding environment. In addition to ductility, RC beams is affected by cracking and deflection behavior of RC beam. [4-6].

Consequently, ductility can be defined according to deflections (deflections ductility), strains (strain ductility) and curvature (curvature ductility). Ductility of deflection depends on the entire member configuration and loading of entire acting member. It is defined as the ratio of deflection at ultimate load to the deflection at yield load; the diagram of load-deflection presents this relation. Meanwhile, ductility of strain depends on material type and can be defined as the ratio of strain at ultimate load to strain at yield load; the stress-strain diagram shows such relation. Ductility of curvature depends on the shape and size of the RC member cross section, and can be defined as the ratio of curvature at ultimate load to curvature at yield load; the diagram of moment-curvature draws the relation [7, 8]. To evaluate the ductility index of RC beam with lap splice, the ratio of displacement ductility is selected by Azizinamini et al. (1999a) [8].This index is defined as "the ratio of the maximum mid-span deflection over the first yield deflection of beams (Eq.1).The deflection of the first yield, Δ_v , corresponds to the tangents of the load deflection curveinter section at the origin and maximum deflection", Δ_{max}(Fig. 1a).Therefore, to predict lap-spliced RC beams behavior, the ratio of deflection ductility can be used. This presents a new criterion, in addition to the strength criterion. The study of Azizinamini et al. (1999a) [8] studied RC beams with lap splice length more than those required by ACI Committee 318 (1995) [9] equation. As a result of this study, the specimens satisfied the strength criterion of $u_{test}/u_{ACI} > 1$, and the failure of specimens was violent manner without exhibiting ductility and very brittle. This refers to a lack of transverse reinforcement used over the splices.

Cohn and Bartlett, 1982 [10] proposed a relatively more appropriate definition for the ductility index of displacement. Based on their definition, the ductility index of displacement can be estimated by "the ratio of the displacement corresponding to 85% of the maximum load on the post-peak portion of the curve to the displacement corresponding to the first yield displacement of a beam" (Eq. (2) and Fig. 1b). It should be noted that since the displacement at peak load may not represent yielding of reinforcement, the term c is used instead of y.

$$i = \frac{\Delta_{max}}{\Delta_y} \quad (eq.1)$$

$$i = \frac{\Delta_{0.85}}{\Delta_c} \quad (eq.2)$$

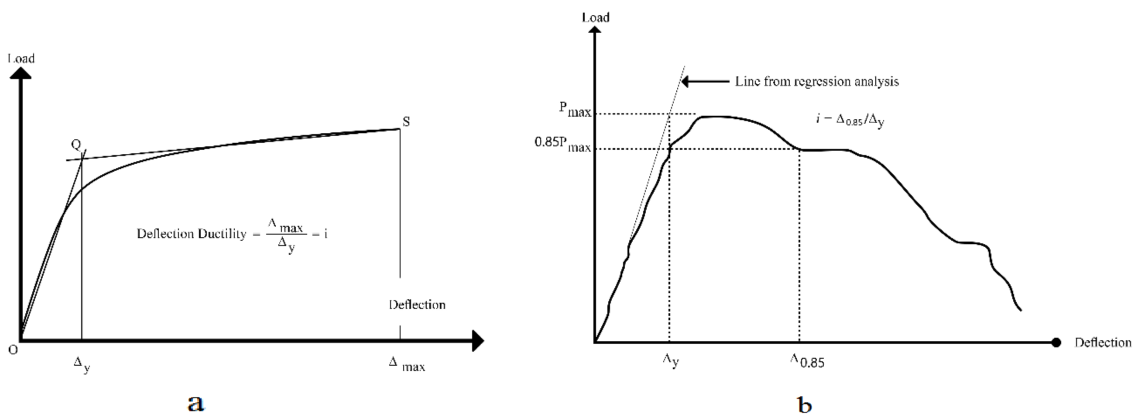


Figure 1 - Definition of displacement-ductility ratio.

Fire is considered one of the serious causes of damage and cause collapse of reinforced concrete structures. Many collapse cases took place in recent years due to fire all over the world [10-11]. The effect of fire on structural safety is dependent on fire temperature, duration and firefighting technique [12-13]. Any member of reinforced concrete (RC) structures may be exposed to hazard such as; fire, concrete cover of RC beam can protect the steel reinforcement for limited time and moderate temperature. Unfortunately, the RC beams with lap splices mainly depends on the bond strength between rebar reinforcement and concrete, and these bond behavior is affected by fire [14-17]. To evaluate the effect of high temperature on bond strength, Ammon Katz,1999[6] presented four different type of tested Fiber reinforced polymer (FRP) rebar compared to ordinary steel rebar; the nominal diameter of steel was 12 mm and for FRP rebar was 12.7mm. Each rebar was placed vertically in the mold of a cylinder with a 150 mm diameter and 300 mm length before casting with total embedment length of 120mm. In order to measure the temperature, a thermocouple was placed near the rebar in mold before casting. The specimens were heated up to250 ℃, then, the pullout test started. The results showed that the bond strength of FRP rebar was reduced in the range of 80%- 92% depending on the surface type of FRP rebar. While, for steel rebar, the bond strength lost about 38%. Magda, 2015[18] developed an experimental program of eighteen spliced beams to investigate the ductility and

flexural behavior of RC beams with lap splice in High strength concrete. The parameters considered in this study were: bar diameter, amount of transverses, shape of anchor at splice end, splice length and concrete cover. Results show that, the ductility ratio increased by approximately 48% for beams that has confinement provided by transverse stirrups. In addition, the failure became more ductile when used hooks at the end of splices bar, and an increase in ultimate load and cracking. Then, an empirical equation for prediction of bond strength based on the results of different series of experimental works proposed by Orangun et al. [19]. Later on, this equation became the basis of the ACI Committee 318[2].

Generally, it can be seen that design codes such as ACI 318-14[2] and ECP 203-2007 [3] Euro Code2-1996 [20] do not take the effect of fire on ductility behavior of spliced RC beam into consideration. Based on the above, there is a lack of data related to the effect of fire on lap splices as it has not yet been fully investigated. In this research, the main objective was to investigate the effect of fire on the flexural ductility behavior of reinforced concrete beam with lap splice. The lap splice is introduced at the bottom surface "tension zone" of constant moment and with constant splices length and reinforcing bar size. This investigation is carried out in terms of flexural crack pattern, bond strength, and displacement ductility. The effect of different factors such as concrete cover (20mm &30mm), fire temperature (650 ℃&800 ℃) and exposure time (1hr, 2hrs &3hrs) was investigated.

2 EXPERIMENTAL PROGRAM

The test program has been developed to study the effect of fire on the flexural ductility behavior of reinforced concrete beam with tension lap splice. The considered variables; concrete cover (20mm&3mmm), fire duration (1hr, 2hrs &3hrs) and temperature value (650 ℃ &800 ℃). It consisted of thirteen simply supported RC beams with lap splices, divided into two groups with different concrete cover. One spliced RC beam was a control beam (non-fired), while, each group contains six RC beams exposed to fire; in which three beams exposed to fire at temperature value of 650 ℃ for 1hr, 2hrs &3hrs, respectively while the other three exposed to fire at temperature value of 800 ℃ for 1hr, 2hrs &3hrs, respectively. Details of the experimental program are summarized in table (1). The notation specimen C2-T650-Ex2 means; C2: concrete cover is 20mm, T650: Fired at temperature of 650˚C and Ex2: the exposure time of fire is 2 hours.

Table1- Experimental Program details

No.	Specimen Notation	Cover Thickness	Temp. (C)	Fire duration (hrs)	Remarks
B1	C-T0-Ex0	2	-	-	Control
B2	C2-T650-Ex1	2	650	1hr	Constant Temp. & changing duration
B3	C2-T650-Ex2	2	650	2hrs	
B4	C2-T650-Ex3	2	650	3hrs	
B5	C2-T800-Ex1	2	800	1hr	Constant

B6	C2-T800-Ex2	2	800	2hrs	Temp. & changing duration
B7	C2-T800-Ex3	2	800	3hrs	
B8	C3-T650-Ex1	3	650	1hr	Constant Temp. & changing duration
B9	C3-T650-Ex2	3	650	2hrs	
B10	C3-T650-Ex3	3	650	3hrs	
B11	C3-T800-Ex1	3	800	1hr	Constant Temp. & changing duration
B12	C3-T800-Ex2	3	800	2hrs	
B13	C3-T800-Ex3	3	800	3hrs	

2.1 Design and construction of lap-spliced RC beam specimens

2.1.1 Materials

In this experimental program, ordinary Portland cement (Type I) was used to produce concrete mix, the natural siliceous sand with a specific gravity of 2.41 and fineness modulus of 3.25 used as fine aggregate. However, gravel of 10 mm nominal maximum size with a specific gravity of 2.54 was used as coarse aggregate. The longitudinal tensile reinforcing bars with nominal 12 mm diameters and transverse bar with nominal 8 mm diameters, were used in the RC beams. The yield stress of three tested reinforcing bars of 12mm were found to be 552, 552, and 561 MPa, respectively, and the average yield of 8mm bar were 318 Mpa by a tensile test process in the laboratory of Housing & Building National Research Center; Giza, Egypt (HBRC). A local ready-mix supplier of concrete for beam specimens was provided by mechanical mixer (with volume of 1/7 cubic meter). The 30Mps compressive strength of mix-design concretes were used for the beam specimens. Proportions for 1 cubic meter (400 Kg cement, 1150 Kg course aggregate and 635 Kg fine aggregate), to check workability of concrete mix, the slump was 90mm Fig.2. Also, the W/C ratios were 0.50.

Figure 2 - Slump test for fresh concrete

Figure 3 - wooden mold of beam.

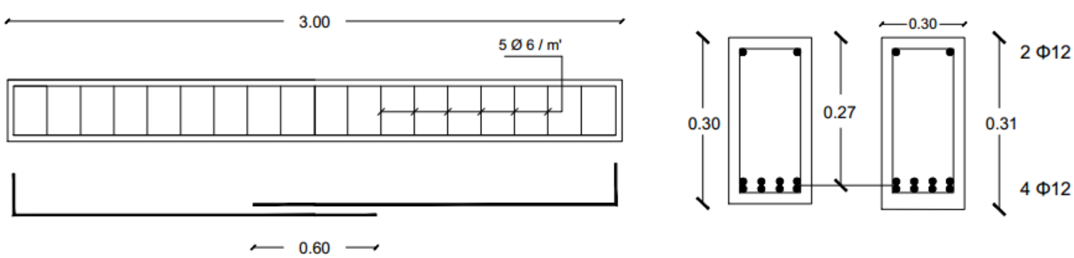


Figure 4 - Details of reinforcement and concrete dimensions of beams.

Figure 5 - a. The Fire Furnace, b. fire setup for beam.

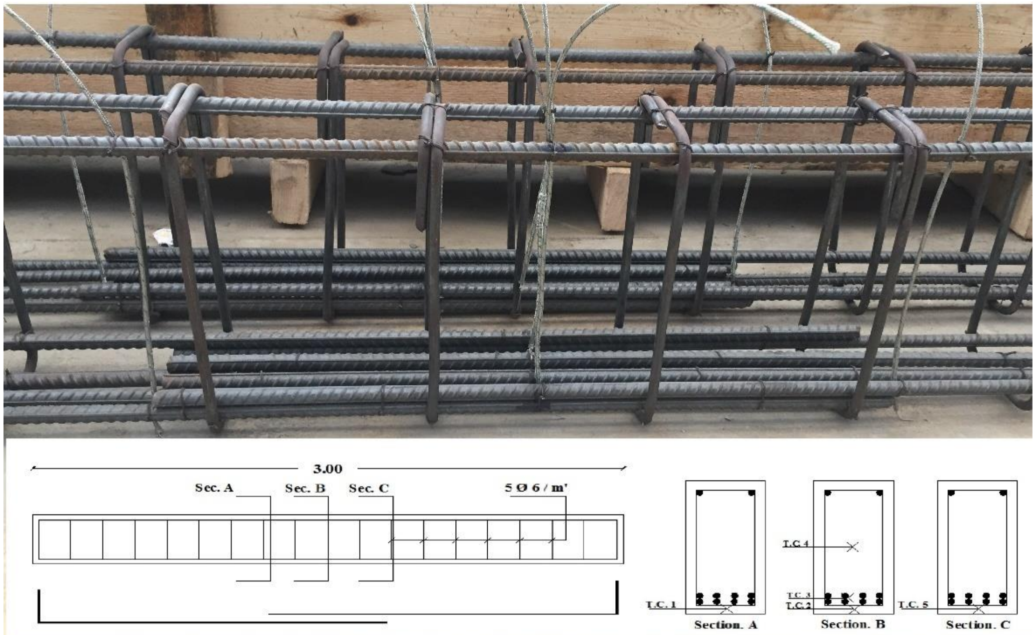


Figure 6 - Thermocouples' Nodes Arrangement in each Section

Figure 7 - Test Setup

2.2 Beam Specimens

Thirteen RC beams with lap splice have been cast to test in Housing & Building National Research Center (HBRC) laboratory, Giza, Egypt. A 300 X 150 mm cross section and a length of 3000 mm, cover thickness for all side equal 20 mm except the bottom variable side, cast in stiffed wood mold as show in Fig.3. As cited in test program, the specimens of concrete cover 30mm, the increased were in bottom cover only as shown in Fig.4 and the depth became 310mm to be conservative on same effective depth "d" for all RC beams. Four bars of 12 mm was used as bottom longitudinal reinforcement and two 12 mm was used as top reinforcement, bars of 8 mm was used as transverse reinforcement. The lap spliced length estimated to be 600 mm according to EC203-2007[3] for all RC beams as shown in Fig.4. Specimens casted in HBRC laboratory and cured for 28 days. After that, twelve of RC beams transfer to fire laboratory. A 900X900 mm top open and 1100 mm height furnace has been used, as shown in Fig.5a. The RC beams placed at the top open of furnace as shown Fig.5b. The beam was fired from bottom (spliced) surface with length of 900 mm at the middle of beam as shown in Fig.5b. With different temperature and duration according to the experimental program with furnace time history of ISO 384[21], the furnace contained a temperature control system which had the ability to control the rate temperature increase till 1000℃ by using thermocouples (Type-K). Five thermocouple (Type-K) attached to concrete and steel reinforcement in RC beams before casted. In fire stage, thermocouple connected to data logger to record (measure) concrete and steel reinforcement temperate as shown in Fig.6. After applying the known duration and temperature according to experimental program, specimens have gradually cooled by air.

After firing the RC beams, all beams painted with white diluted of lime solution to ease cracks propagation in the test stage. The beams were supported over rod and palate (roller & hinged). The beams were tested two concentrated loads to achieve pure moment as shown in Fig.7. A hydraulic jack of 500 kN for loading the beam was used. The jack was attached to an electrical load cell with 500 kN capacity. Three Linear variable distance transducers, (LVDT) with 100 mm lengths were attached to the bottom surface of beam to record the deflection. The test beams are shown in Fig.7.

3 EXPERIMENTAL RESULTS

3.1 Temperature of Beams

For each beam, temperature was measured at five points; distributed in three sections as show in Fig.6. Table 2 shows the measured temperature of each fired beam, since Thermocouple1 (T.C.1), (T.C.2) and (T.C.5) placed in concrete cover at start, mid and end of splices, respectively. (T.C.3) placed on reinforcement bar and (T.C.4) placed at the center of beam section. Readings of thermocouple were recorded every 10 minutes, Table2 gives reading at the end of exposure time of fire for each beam. Beams with concrete cover of 30 mm have reading temperature less than beams with concrete cover of 20 mm at similar conditions (Furnace temperature, Exposure Time). It was observed that, the temperature increases gradually in the upward direction, in addition to an increase in the heat propagation in the fired beams due to reinforcing bar diameter increase.

Table 2 - Summary Temperature of Fired Beam.

No.	Beam Notation	T.C. 1	T.C. 2	T.C. 3	T.C. 4	T.C. 5
B1	C2-T0-Ex0 (control)	-	-	-	-	-
B2	C2-T650-Ex1	234	219	195	55	210
B3	C2-T650-Ex2	321	305	275	85	317
B4	C2-T650-Ex3	398	372	358	125	388
B5	C2-T800-Ex1	329	343	261	75	345
B6	C2-T800-Ex2	443	489	340	111	493
B7	C2-T800-Ex3	528	519	475	209	558

B8	C3-T650-Ex1	209	195	165	52	213
B9	C3-T650-Ex2	286	276	233	62	268
B10	C3-T650-Ex3	355	341	301	91	332
B11	C3-T800-Ex1	285	268	191	61	261
B12	C3-T800-Ex2	411	412	318	101	427
B13	C3-T800-Ex3	499	486	421	180	475

Crack propagation and Load-deflection were recorded for each tested beam. Fig.8 show the crack propagation of (C2-T0-Ex0 "control") and (C3-T800-Ex2), the failure of control beam (non-fired) is ductile "flexural failure" and the reinforcing bar reach to yield with large displacement with conservative on bond strength. Meanwhile, the failure of beam (C3-T800-Ex2) is brittle (splitting failure) with small displacement and losses on bond strength.

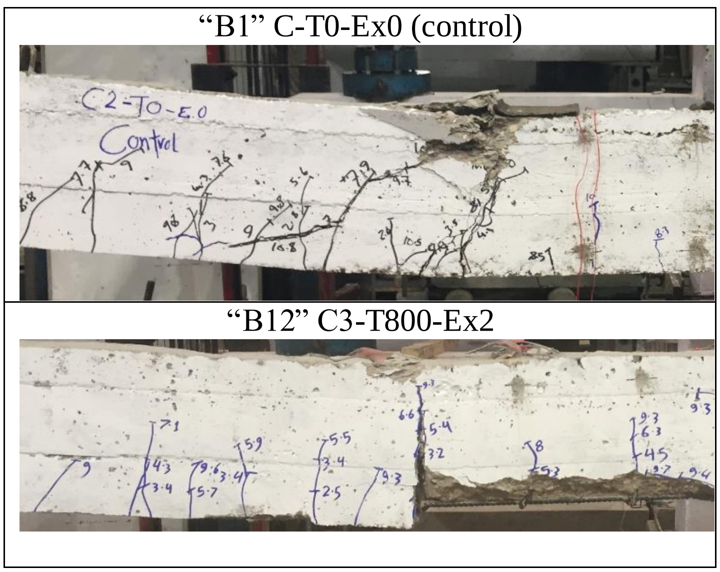


Fig.8 - Crack propagation of tested beams.

Bond Strength of control beam was calculated by equation of ACI code eq. (2) and compared with experimental bond strength (u_{test}), the value of experimental bond strength calculated by eq. (3) as follows:

$$u_{test} = \frac{A_b f_s}{\pi d_b l_d} \quad (3)$$

Since the length of splice (l_d) was calculated using eq. (ACI), where, A_b is the area of the reinforced bar, d_b is the bar diameter and $f_s$is the tensile bar stress; calculated by eq. (4) as follows:

$$f_s = \frac{M_{test}}{A_s jd} \quad (4)$$

Since the value M_{test} is the maximum bending moment at failure ($M_{test} = 1.2p_{test}/2$) and jd is the moment of arm. The parameter j is calculated based on the elasto-plastic analysis by (*j=1-k/3*); since $k = \sqrt{2n\rho + (n\rho)^2} - n\rho,\ where\ \rho = A_s/bd\ ,\ n = E_s/E_c, E_s = 220000\ Mpa\ and\ E_c = 4700\sqrt{f'_c}\ Mpa$. In the beam section, A_s is not doubled because of the splices according to (Azizinamini et al. 1999a; Esfahani and Rangan 1998b. where used strain gage reading of reinforcing bars to verify this suggestion in them research. And the longitudinal bar ratio ρ is less than maximum ratioρ_{max}.)

Table 3, summarized the results including the notation beam, the ultimate loads, tensile bar stress, the value of experimental bond strength, for different tested beams. The ductility ratio was calculated according to Cohn and Bartlett (1982) [10] by eq. (2) and presented in column 7, the value of Δ_y and $\Delta_{0.85}$ presented in column (5 & 6) respectively.

As shown in column 2 in Table 3, P_{test} of beam C-T0-Ex0 (control) is 109.4 kN is the largest value; as this beam satisfied the design code and not-fired. When comparing beam C2-T800-Ex2 (fired for 2 hours with 800℃ temperature) with control beam, the ultimate load of (C2-T800-Ex2) is 76.6 kN. This indicates that the fire has major effect on RC beam with lap splice, since this beam (C2-T800-Ex2) loss about 30% of ultimate load. All value of P_{test} clearly presented in column 2, the losses of ultimate load is 5% to 35%, where increase temperature and fire duration decrease the ultimate load, the increase in concrete cover increases (conservative on bond strength) the load capacity for fired beam with lap splices.

Table 3 - Test results of different RC beams.

Beam Number	Beam Notation	$P_{test}(kN)$	$f_s(Mpa)$	$u_{test}(Mpa)$	$\Delta_y(mm)$	$\Delta_{0.85}(mm)$	$i = \frac{\Delta_{0.85}}{\Delta_y}$
B1	C-T0-Ex0	109.40	658.18	3.29	16.4	88.85	5.42
B2	C2-T650-Ex1	95.70	575.76	2.88	12.91	29.65	2.29
B3	C2-T650-Ex2	89.90	540.86	2.7	12.05	19.20	1.59
B4	C2-T650-Ex3	79.40	477.69	2.39	9.53	14.90	1.56
B5	C2-T800-Ex1	84.20	506.57	2.53	12.68	21.45	1.69
B6	C2-T800-Ex2	76.60	460.85	+2.3	11.92	17.89	1.50
B7	C2-T800-Ex3	71.30	428.96	2.14	10.73	15.92	1.48
B8	C3-T650-Ex1	103.40	621.34	3.11	13.43	44.20	3.29
B9	C3-T650-Ex2	100.30	603.43	3.02	13.04	34.75	2.67
B10	C3-T650-Ex3	95.50	574.55	2.87	12.42	27.15	2.19
B11	C3-T800-Ex1	101.5	610.65	3.05	10.86	56.40	2.58
B12	C3-T800-Ex2	93.00	599.51	2.8	12.09	20.35	1.68
B13	C3-T800-Ex3	84.40	507.77	2.54	11.56	19.00	1.64

3.2 Effect of fire on bond strength

Column 4 in table 3 shows the bond strength of each beam, where the equation of ACI code and Egyptian code did not consider the effect of fire. So, the bond strength that calculated is the experimental value, for control (non-fire) beam the bond strength calculated by code to give 2.76 Mpa. For fired beam, the value of bond strength deceases as the temperature increases, beam (C2-T650-Ex3) has value of bond strength equal 2.39 Mpa, for other beam with similar condition except temperature value changed from 650 ℃ to 800 ℃ (C2-T800-Ex3), the bond strength equal 2.14, that's mean; bond strength loss about 10% when increase the temperature form 650 ℃ to 800 ℃. When comparing these value with experimental value of non-fire beam, the reduction in bond strength equal 27% & 35% for (C2-T650-Ex3) and (C2-T800-Ex3).

Increasing the fire exposure time from 1 hour to 3 hours for all tested beams, decreases the value of bond strength, where (C2-T800-Ex1), (C2-T800-Ex2) and (C2-T800-Ex3) have bond strength 2.53, 2.30 and 2.14 respectively. Compared these values with non-fired beam bond strength =3.29, the reduction in bond strength, with an increase in exposure time, found to be 23%, 30% and 35% respectively. This reduction of bond strength

depends on other condition as temperature and concrete cover.

The lap splice mainly depends on bond between reinforcing bar and concrete. Thus for structures exposed to fire, the concrete cover protects the reinforcing bar, RC beams with lap splices is affected by fire. Concrete cover reduces the hazard effect of fire on bar reinforcing. Therefore, for RC beams with lap splice, it has been proved that the concrete cover protects bond strength of the lap splice. As, increasing the cover from 2 cm to 3 cm (with same other conditions) results in an increase in bond strength, for beam (C2-T650-Ex1) and (C3-T650-Ex1) the bond strength increases from 2.88 Mpa to 3.29 Mpa, beams with temperature 800 ℃, increases cover for (C2-T800-Ex1) & (C3-T800-Ex1) bond strength changed from 2.53 to 3.05Mpa, so the bond increase for about 20%. An increase of one cm in concrete cover increases bond strength for approximately (11% to 20%), that's mean that the concrete cover has a main effect in protecting the bond strength of RC beam with lap splices when exposed to fire. All results presented above agreed with the results of AmmonKatz, 1999 [6]. The reduction in the bond strength between reinforcing bar and concrete could be attributed to the loss of concrete strength at elevated temperature due to internal vapor pressure.

3.3 Effect of fire on deformability and ductility

Fig. (9) represented the load versus mid-span deflection curves for all test RC beams. Also, the deflection of $\Delta_{0.85}$ and Δ_y of all beams are shown. The value of $\Delta_{0.85}$ and Δ_y are displayed in table 3. For Beams (B3, B4, B5, B6, B7, B13) the value of the yield stress F*y* is larger than the value of tensile stress of reinforcing bar F*s*. Therefore, the term of ductility ratio cannot be used for these beams. In fact, the ratio *i* is the deformability ratio (Mehrollah Rak. 2014) [1]. As shown in table 4 column8, the ductility ratio for B1 (non-fire) (i=$\Delta_{0.85}/\Delta_y$=5.42), ductility ratio of B2 (C2-T650-Ex1) equal (i=$\Delta_{0.85}/\Delta_y$=2.29) is relatively low compared to B1 (control); due to the effect of fire on splices. Beam 3 and 4 have deformability ratio (i= $\Delta_{0.85}$ / Δ_y =1.59) and (i=$\Delta_{0.85}/\Delta_y$=1.56), respectably. This means that the effect of fire duration, form 2hrs to 3hrs, on ductility is low for beam of 2cm concrete cover.

Form Fig.9 (B5, B6 &B7), the value of deformability ratio (i=$\Delta_{0.85}/\Delta_y$) equal 1.69, 150 and 1.48 for B5 (C2-T800-Ex1), B6 (C2-T800-Ex2) and B7 (C2-T800-Ex3), respectively. It shows that, the variation in deformability ratio is very low when increasing the fire duration form 1hr to 3hrs. Comparing these value with control beam, the reduction of deformability ratio is about (68% to 72%), confirming that the effect of temperature is larger than the effect of fire duration.

For Fig.9 (B8, B9 &B10), the value of deformability ratio (i=$\Delta_{0.85}/\Delta_y$) equal 3.29, 2.67 and 2.19 for B8 (C3-T650-Ex1), B9 (C3-T650-Ex2) and B10 (C3-T650-Ex3), respectively. The reduction in ductility ratio is 9.8% and 39% when increasing the fire duration from 1hr to 3hr. In these beams, the fire duration has major effect on ductility ratio, where the ratio reduction is about 39% in comparison with the previous beams (B5, 6 &7); as the ratio were 12%. When comparing the beams (B8, 9 &10) with control (non-fired), the reduction in ductility ratio equal 45%, 50% and 59%.

For Fig.9 (B11, B12 &B13) the deformability ratio (i=$\Delta_{0.85}/\Delta_y$) equal 2.58, 1.68 and 1.64 for B11 (C3-T800-Ex1), B12 (C3-T800-Ex2) and B13 (C3-T800-Ex3), respectively. The reduction in ductility ratio is 34% and 36% when increasing the fire duration from 2hr to 3hr (taken B11 as reference). In these beams, the fire duration has major effect on ductility ratio when increasing duration form 1hr to 2hrs, but from 2hrs to 3hrs, it has no effect. When comparing the beams (B11, 12&13) with control (non-fired), the reduction in ductility ratio equal 52%, 69% and 70%, respectively.

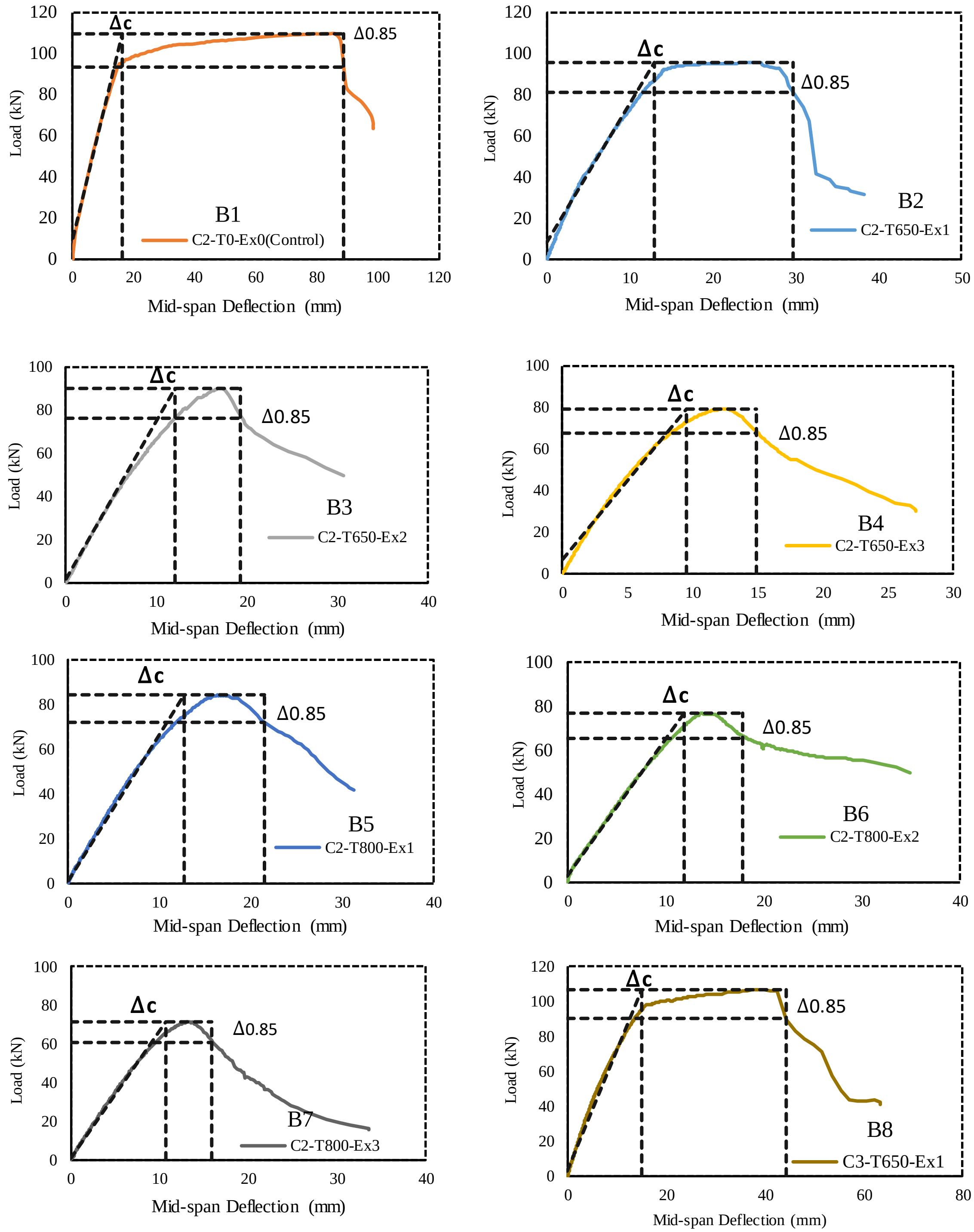
Fig.10 shows the effect of concrete cover on the ductility ratio for fired tested beam, where vertical axis is the ductility ratio and the horizontal axis is the beam named, C3 and C2; the thickness of concrete cover 2cm or 3 cm. For each group, the value of ductility ratio with different concrete cover under similar conditions (temperature variation & exposure fire duration) were compared. It can be seen that, the beams with concrete cover 3 cm has a higher ductility ratio than beams with 2cm concrete cover. The concrete cover has a main effect on ductility ratio except for beams exposed to a temperature of 800 ℃ and duration 2 and 3 hrs. That's mean, concrete cover can protect the RC beam with splices.

Fig.11 A comparison between beams with similar conditions but different fire exposure duration is drawn. It can be seen that increasing the duration from 1hrs to 2hrs for all beams largely affect the ductility ratio, the reduction is (34%, 10%, 34) respectively. On the other hand, an increase in fire duration from 2hrs to 3hrs has a low effect (less than 2%) on ductility ratio except beam with concrete cover 3cm and temperature of 650 ℃. As, it has a reduction of 18%, the cover has main effect with temperature 650 ℃.

4 CONCLUSION:

To study the effect of fire on the flexural ductility behavior of reinforced concrete beam with lap splice, thirteen RC beams with lap splice were casted, fired and tested. Test results were compared to investigate the effect of fire on bond strength and ductility of RC beam with lap splice. Based on test experimental results, the following conclusions can be drawn/ documented:

1. The RC beams with lap splices mainly depend on the bond strength between reinforcing bar and concrete.
2. The fire has main effect on the bond strength of RC beams with lap splices.
3. As increasing fire temperature from (25 to 650 ℃) & (25 to 800 ℃), a reduction in bond strength were about (12% to35%) for beam with concrete cover 2cm, depending on the duration of exposure fire.
4. As increasing fire temperature from (25 to 650 ℃) & (25 to 800 ℃), a reduction in bond strength was about (2% to 23%) for beam with concrete cover 2cm, depending on the duration of exposure fire.
5. Increasing concrete cover from 2cm to 3cm can be more conservative on bond strength of RC beams.
6. The ductility ratio of RC beams is mainly affected by fire. Increasing temperature value from (650 ℃ to 800 ℃) reduced the ductility ratio (45% -75%).
7. Although it is found that providing enough concrete cover for RC beams with lap splices, exposed to fire, can achieve a satisfactory ductility ratio. The results show that increasing concrete cover from 2cm to 3cm results in ductility response.
8. The reduction in ductility response due to circumstances of fire in RC beams with lap splices needs to be considered in design codes.


B1
C2-T0-Ex0(Control)
Δc
Δ0.85
B2
C2-T650-Ex1
B3
C2-T650-Ex2
B4
C2-T650-Ex3
B5
C2-T800-Ex1
B6
C2-T800-Ex2
B7
C2-T800-Ex3
B8
C3-T650-Ex1
Load (kN)
Mid-span Deflection (mm)

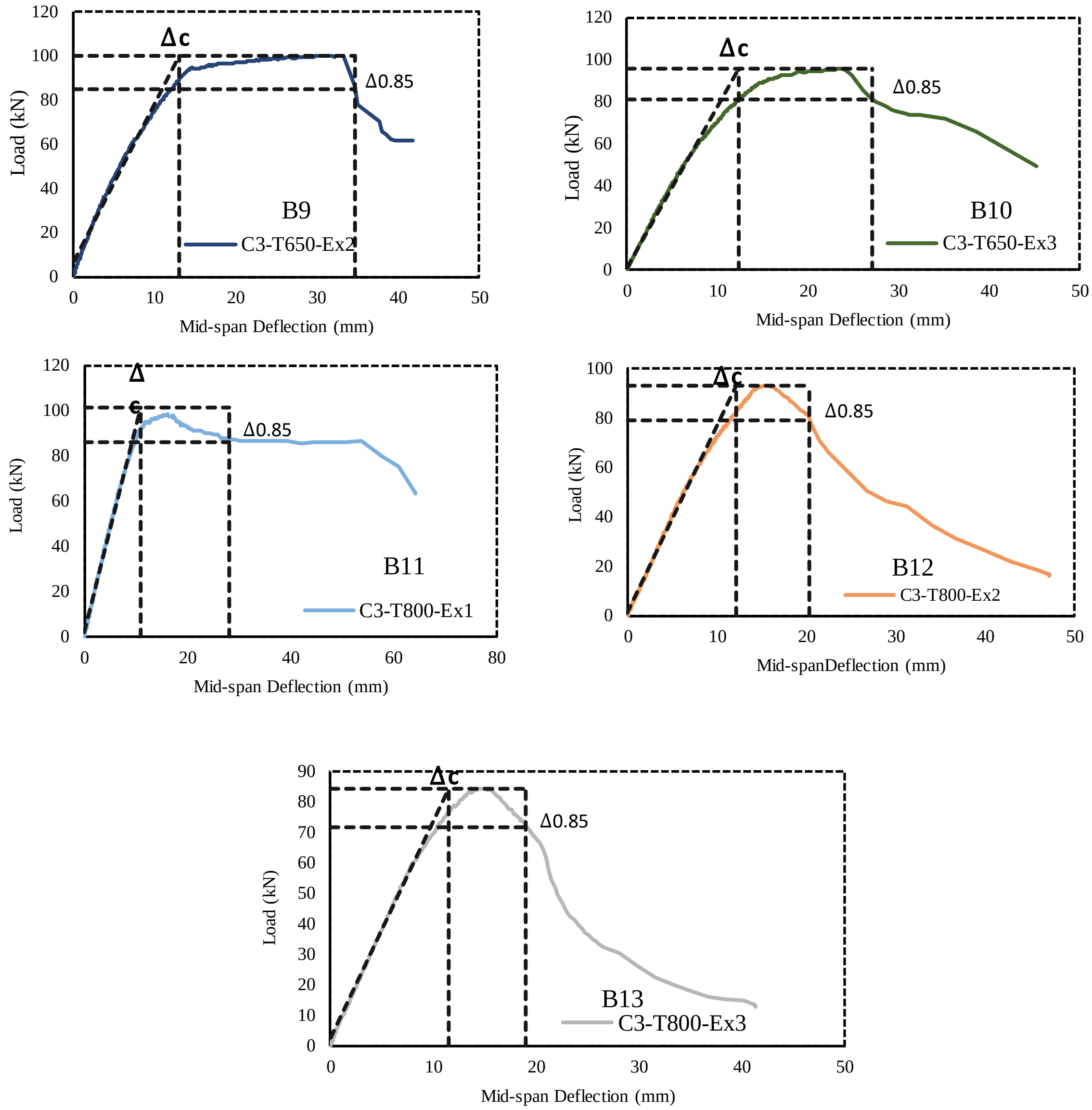


Figure 9 - Bond Strength and ductility of Different beams.

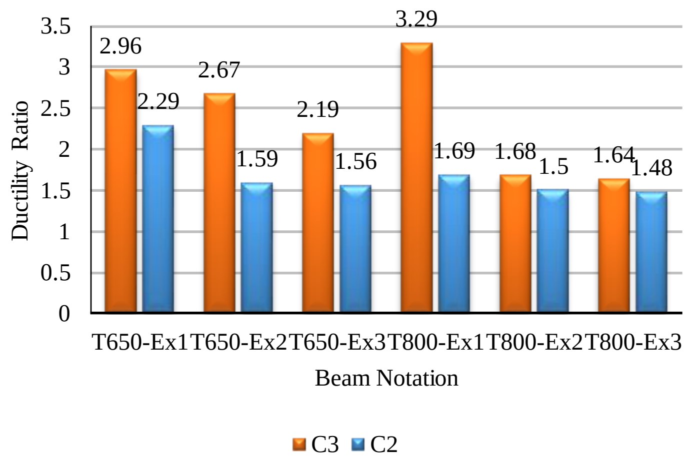


Figure 10 - Compression of beam with different concrete cover.

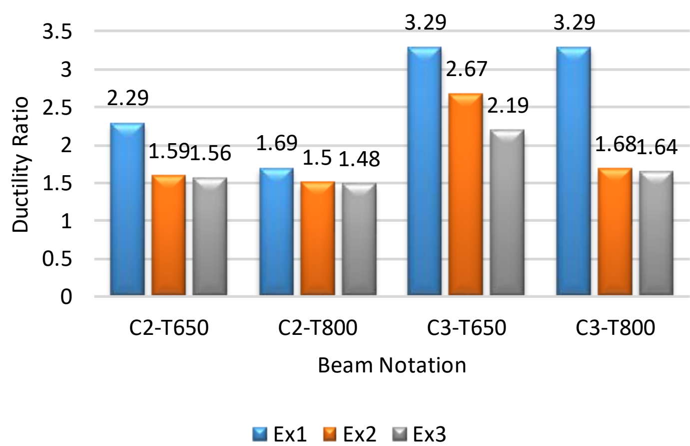


Figure 11 - Effect of temperature variation on ductility ratio.

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