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Article

Residual Strength of Composite Unprotected Steel-Deck Floor Exposed to High Temperature (Fire Flame)

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Abstract. An experimental programme was conducted to find out the behaviour of composite unprotected steel beam-reinforced concrete SB-RC deck floors fabricated from three secondary steel beams welded to another two main beams topped with a reinforced concrete slab, exposed to high temperature (fire flame) of 300, 500 and 700ºC for 1 hour, then allowed to cool down by leaving them at lab condition to return to ambient temperature. The burning results show that, by exposing them to a fire flame of up to 300 ºC, no serious amount of permanent deflection can result. It was also seen that the middle and lateral secondary steel beams have recovered 92 and 95% of the deflection caused by heating, respectively. While the recovered deflection of burned composite SB-RC deck floor at 500 ºC was 46 and 45 %, respectively. The greatest deterioration was in the exposure to 700 ºC, as this leads to a higher permanent deflection of the middle and the lateral secondary steel beams, and the recovery percentage was only 11 and 18 %, respectively. Then all composite SB-RC deck floors loaded till failure to determine percentage decrease in ultimate capacity. The results were compared with the behaviour of composite SB-RC deck floor without burning (reference specimen). The comparison shows that the pre-burned composite SB-RC deck floor at 300, 500 and 700ºC, gives a decrease in specimens' stiffness compared with the unburned one, by about 17, 61 and 74 % for the middle secondary steel beam, and 25, 62 and 75 % for the lateral ones, respectively. Likewise, linearity behaviour of the load-deflection curve decreases and the curves become flatter as the burning temperature increased. Also, the residual ultimate strength capacity decreases as the burning temperature was increased. For the burned composite deck floors at 300, 500 and 700 °C, it was 87, 64 and 38 %, respectively, compared with the unburned specimen.

Keywords: Burning, fire flame, high temperature.

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1. Introduction

The behaviour of composite unprotected steel beam-reinforced concrete (SB-RC) deck floors has been the subject of many studies over a number of years due to different types of accidents and terrorism.
In any flame, the strain comprises four parts: thermal strain, mechanical strain, creep strain and transient strain [1].

Material properties of steel and concrete at elevated temperatures has been extensively studied. The stress-strain relationships and the thermal properties of steel are specified by many researchers [2, 3, 4] as well as by the Eurocode EN 1993-1-2 (EC3) (2005), likewise that for concrete [6, 7, 8, 9]. According to EN 1993-1-2 (EC3) (2005), the elastic modulus and yield strength of steel stay unaltered till they reach a temperature of 100 and 400˚C, respectively. The residue of these properties at 500˚C are 60 and 78 %, and at 700 ºC they reached up to 13 and 23 %, respectively. On the other hand, according to EN1992-1-2. (2004), as temperature increases, the peak concrete compressive strength reduces, whereas the corresponding strain increases. The residual compressive strength reaches up to 85, 60 and 30 % at a burning temperature of 300, 500 and 700˚C, respectively.

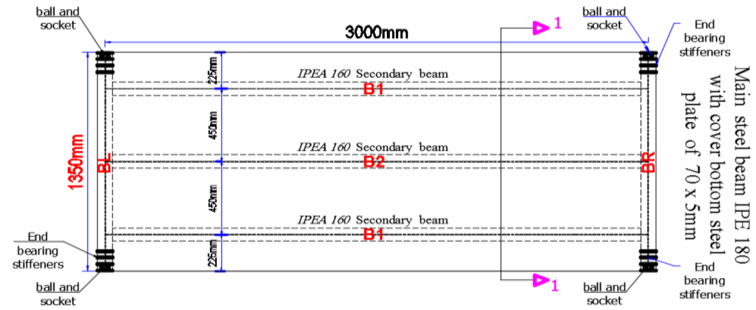
Bailey et al. [11] and Newman et al. [12] studied the behaviour of composite steel beams with steel decking, they observed that the steel beams lost significant strength and stiffness with the deboning of steel decking.

Zhao et al. [13] tested two full scale composite floor systems with two different steel and concrete slabs, for more than 120 minutes. In these tests, the slabs did not collapse even though the interior secondary beams were unprotected, the slabs failed in terms of integrity. Zhang et al. [14] tested four steel-concrete composite slabs. On the basis of the test observations, they developed a method to estimate the load capacity of reinforced concrete slabs under fire conditions taking into account the tensile membrane action. In these tests, cracks were formed along the long edges of the slabs. Wellman et al. [15] conducted a series of small-scale tests on composite floor assemblies under fire loading. They observed that the failure mechanism of the tested specimens included failure of the interior beams, followed by failure of the edge beams.

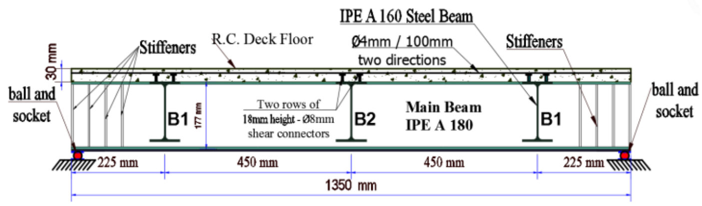
In this study, a comparison was made by testing system of loaded multi-unprotected composite SB-RC deck floor each has been exposed to fire flame with its companion gasses of a different burning temperature of 300, 500, 700 ºC, to find the residual reversibility and ultimate strength of this type of composite structures. The research is focused on structural behaviour, rather than thermal behaviour of the members.

2. Fabrication of Specimens

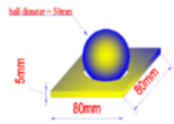
A composite SB-RC deck floor of 12 m and 14.4 m span length and width, respectively, simply supported by boundary conditions at each edge corner was selected and designed. Along with this, nine secondary beams spaced at 1.8 m welded to two main beams are required. From the midzone of the chosen span parallel to the secondary beams, three beams were selected in addition to the portion of the main beams they were connected with. Then, to get the nearest simulation of reality, the geometry and the applied load were scaled down. The experimental programme was executed by four simply fabricated supported scaled-down composite SBRC deck floors (SB-RC deck floor) modeled by a geometry factor of (1/4) for all specimen dimensions and other design requirements (stiffeners, shear connectors and deck floor reinforcements) [16]. Each specimen was built up of three steel rolled I-beams spaced at 450 mm, with clear span lengths of 3 m welded to two main beams. Total specimen width was 1.35 m, as shown in Fig. 1. A rolled steel section of IPEA 160 was used to model the secondary steel beams B_2 and B_1, while the two main beams B_R and B_L were modeled by another section of IPEA180, with additional steel plates of 70 mm width and 5 mm thickness that were welded to the lower flange. 1(b)). Shear connectors were designed according to AISC [17], then scaled down by the same geometry factor, accordingly, medium carbon steel bolts of 8 mm diameter, total length of 18 mm and had 393 and 510 MPa yield and ultimate tensile strength, respectively. These were welded using fillet weld type E70XX in two rows with pitch of 100 mm through a distance of L/4 of span length from each support and 125 mm through the midspan portion. A steel sheet of 0.18 mm thick was used to simulate the corrugated sheets formwork required to pour concrete deck floor of 35 MPa cylinder strength (100 mm diameter, 200 mm length) at 28 days and 30 mm thick was adopted, reinforced in two directions with deformed bars of 4 mm diameter spaced at 100mm, 623 and 789 MPa its yield stress and ultimate strength, respectively, positioned at the upper third of the concrete thickness. To simulate the composite SB-RC deck floor self-weight and the permanent dead load an additional uniformly distributed load of 5.4 kN/m^2 (550 kg/m^2) was used to reflect similar specimen stresses as that in the full-scale deck floor.



(a) Plan of of composite RC-RC deck floor.



(b) Section 1-1, details of the composite SB-RC. deck floor.



(c) Ball and socket support.

Fig. 1. Modeled composite SB-RC. deck floor.

3. Tested Composite SB-RC Deck Floor Models

Two stages of experimental tests were carried out as follows:

a) Exposure to high temperature (fire flame): three specimens named as *SB-RC*$_{300}$, *SB-RC*$_{500}$ and *SB-RC*$_{700}$ were exposed to high temperatures of 300, 500 and 700°C, respectively, simultaneously with applied uniformly constant equivalent load. Then they were cooled gradually by leaving them at ambient lab conditions. The temperature was monitored by using digital thermometer readers with thermocouple sensor wires type K fixe at the top concrete surface of the mid span (Fig. 2). The temperature controlled during the burning by the amount of methane gas reach to the nozzles.
The furnace was manufactured by using one 3-mm-thick steel plate having a U-shape to restrict heat from the bottom and sides, and the burned composite SB-RC deck floor from the top, as shown in Figs. 3 and 4. Its dimensions were appropriately matched with the specimen's dimensions so as to leave enough space underneath the composite SB-RC deck floor to reach and disperse the fire flame from the sources (nozzles) to the composite SB-RC deck floor. The nozzles were positioned with 12 in the bottom of the furnace, and four in three rows along the bottom of the specimen, to simulate lower surface fire.

b) Load application test: after finishing the first stage of exposure to high temperature with equivalent load test, all specimens including the fourth specimen (*SB-RC*$_R$) which was left at ambient temperature without burning as a reference, were loaded till failure by distributing the load on all of the specimens' top surfaces as shown in Figs. 5 and 6.
Two sensitivity types of dial gauges were used, 0.001 mm/div. fixed laterally at the end span to find the relative displacement between the concrete deck floor and the steel I beam, and 0.01 mm/div. at mid and end points of each beam to measure the vertical deflection through the two test stages. To measure the midspan longitudinal strain in the bottom flange of the secondary steel beams, three electrical resistances of 6 mm strain gauges were used. The midspan longitudinal and transverse concrete strains above each secondary steel beam were measured by using three electrical resistances of 60 mm strain gauges in each direction. The layout and location of the strain gauges in the composite SB-RC deck floor are shown in Fig 7.

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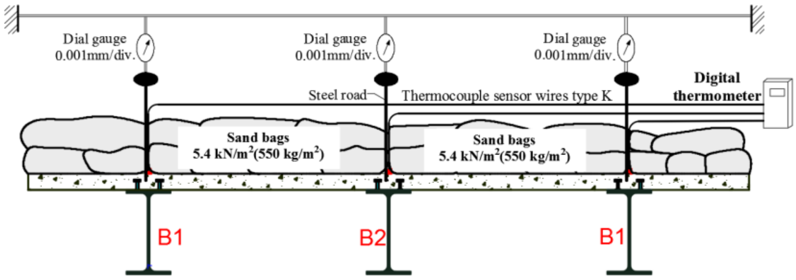

Fig. 2. Cross-section at mid span illustrates the location of dial gauges and thermocouple sensor wires.

Fig. 3. Twelve nozzles to distribute fire flame underneath the specimen.

Fig. 4. Burning of specimen stage (Exposing to fire flam).

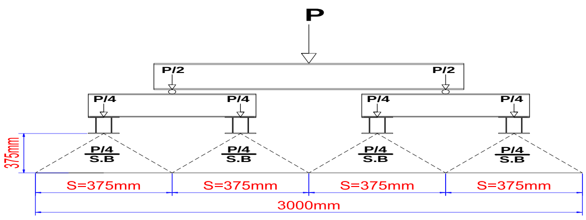

Fig. 5. Distributing applied load on all of the specimen top surface in additinonal to its equivelant distributed load.

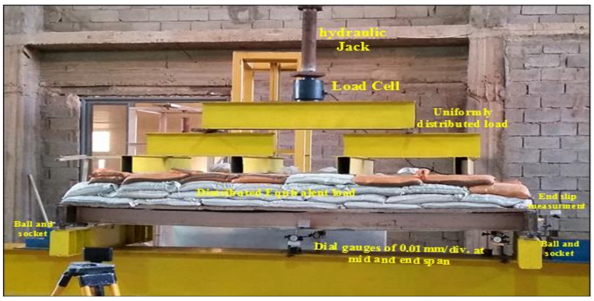

Fig. 6. Test setup through loading stage.

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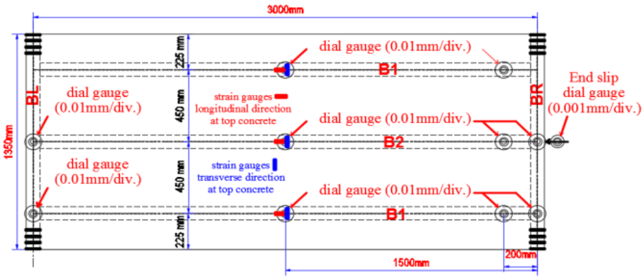

Fig. 7. Location of dial gauges and strain measurements.

4. Results and Discussion

4.1. Steel Beams

Coupon specimens had been prepared according to ASTM-A370 from the steel beam in order to obtain the mechanical properties of steel sections at ambient lab temperature and after exposing to fire flame. In order to achieve the same circumstances of burning and cooling as that of the composite SB-RC deck floors, these coupons had been situated along with them, as well as being cooled in the same manner. Then a tensile test was carried out (steady-state test method). Table 1 shows that with increasing burning temperature the mechanical properties of steel decrease. These results agreed with Chen, and Young [18], in contrast, the EN 1993-1-2 (2005) reported that temperature has no effects on yield strength till 400 °C.

The results of the tensile test at ambient temperature of the reinforcement bars were 623 and 815.6 MPa for yield stress and ultimate strength, respectively, while it was 393 and 510 MPa, respectively, for the shear connectors.

Table 1. Mechanical properties of the rolled steel I-beam.

Burning temperature	Yield Stress (MPa)	Residual yield stress of (burned/reference) %	Ultimate Strength (MPa)	Residual ultimate stress of (burned/reference) %
25°C	360	100	440	100
300°C	328	91	418	95
500°C	252	70	304	69
700°C	76	21	89	20

• coupons thickness 4.0 mm.

4.2. Deflection at Burning and Cooling Stages

Composite SB-RC deck floors were positioned above the idealized simply supported ends. Dial gauges were placed, and initial readings were recorded after the equivalent uniform dead load was applied. Then each of the three specimens was exposed to burning temperature of 300, 500 or 700 ºC for a similar period of 1 hour after reaching the target temperature. The transition period to reach the above target temperatures was approximately 25, 45 and 70 minutes, respectively. Finally, the composite SB-RC deck floors were gradually cooled by leaving the specimens in ambient lab condition.

Figure 8 shows the behaviour of composite SB-RC deck floor burned at 300 ºC, with the specimen having passed through three periods. First was the transition period to reach the target temperature which was approximately 25 minutes. The second period takes 1 hour with a temperature of 300 ºC; and the third was when the fire flame is turned off, which means the cooling period. Through the first period, the secondary steel beam B_2 had a higher rate of declination in midspan deflection than B_1, and it had the highest rate of descending due to being exposed to a high rate of burning. The maximum measured deflection at this period was 16.0 and 6.9 mm, respectively, as shown in Table 2. During the second period, the secondary steel beam B_2 exhibits a low rate of increase in deflection, or approximately no change in midspan deflection, whereas by contrast, a slight sudden increase was observed in the midspan deflection of B_1. At the end of this period, deflection reached 16.4 and 8.6 mm, respectively. The fire sources were underneath the composite SB-RC deck floor, so the heat gain began from the lower parts to the upper parts. This led to the expansion of these parts before the top. Also, the steel thermal conductivity is much higher than that of concrete. This phenomenon gives a high rate of specimen deflection at the first period, but when all specimen parts reached the target temperature, or heat balancing, the deflection rate decreased. Through the final period, a high ascending rate curve was recorded, or in other words, composite SB-RC deck floor tried to recover its original position. Till about 125 minutes of the total time, the composite SB-RC deck floors recover their original positions and continued back rising above its original level before burning for a distance of about 0.3 mm. Because the lower parts of the composite SB-RC deck floor (lower steel flange and web) dissipate heat faster than the upper parts (upper steel flange, concrete deck floor, and the additional dead load), this leads to shrinking of these parts while the upper parts are still expanded. After that, a little increase in deflection was measured and the total time needed to dissipate heat and return to ambient temperature was about 200 minutes of the total time; the residual deflection was 1.4 and 0.4 mm, for B_2 and B_1, respectively, (Table 2). This means that both beams have recovered 92 and 95 % of the deflection caused by heating. So, it can be concluded that when a composite SB-RC deck floor is exposed to fire flame up to 300 °C approximately, no serious amount of permanent deflection can happen.

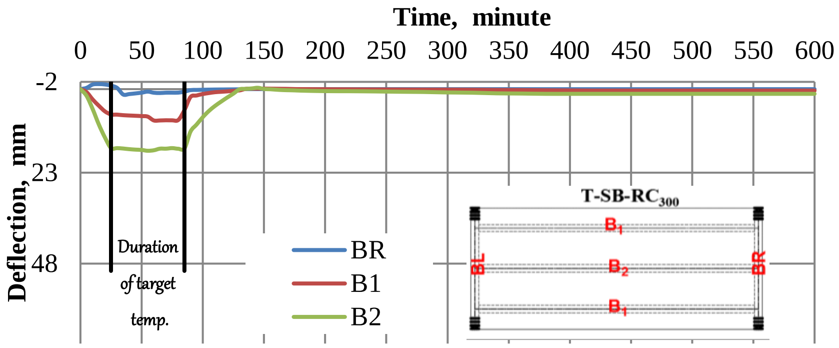

Fig. 8. Mid span deflection-time history of burned beams of composite *SB-RC* deck floor at temperature 300 °C.

Figure 9 shows the deflection of $SB\text{-}RC_{500}$ specimen through the three periods of burning, reaching target temperature of 500 °C, and cooling. Both secondary steel beams showed the same behaviour of a high rate of midspan deflection, but B_2 was more than that of B_1 during the first period which it took approximately 45 minutes of burning before reaching the target temperature. The measured deflection at this time was 35.2 and 19.7 mm, respectively. During the second period of constant burning temperature, the same rate of increase in midspan net deflection was observed. At the end of this period (after 105 minutes), the measured deflection at this moment was 71.4 and 48.8 mm, respectively. The descending of the curves through this period is more than that of burning composite SB-RC deck floor at 300°C. At the beginning of the cooling process, they exhibited a high rate of recovered deflection, but this rate subsided after a short period of time. It can be seen that from time 200 minutes till about 600 minutes, approximately, no deflection is recovered, and the residual deflection was 38.3 and 26.9 mm, which means that the recovered deflection was 46 and 45 %, respectively.

Figure 10 shows the deflection of the burning of a composite SB-RC deck floor at 700 °C. It took 70 minutes to reach the target temperature. The rate of deflection of both secondary steel beams with time was approximately the same through this period, but they were slightly deviated at the end of this period at 111.5 and 99.1 mm, respectively (Table 2). When the specimen burned with a constant temperature of 700 °C through the second period, the rate of descending curves was approximately the same but with a significant deviation between them, B_2 steel beam deformed more than that of B_1, it reached 140.2 and 126.6 mm, respectively, meaning that 10 % is the difference between them. This deviation continued through the cooling period, and a small amount of the total deflection was recovered, the residual deflection was 124.1 and 103.8 mm, respectively, so the percentage of recovered burning deflection was only 11 and 18 %, respectively. This reflects the amount of damage that takes place in both of the secondary steel beams.

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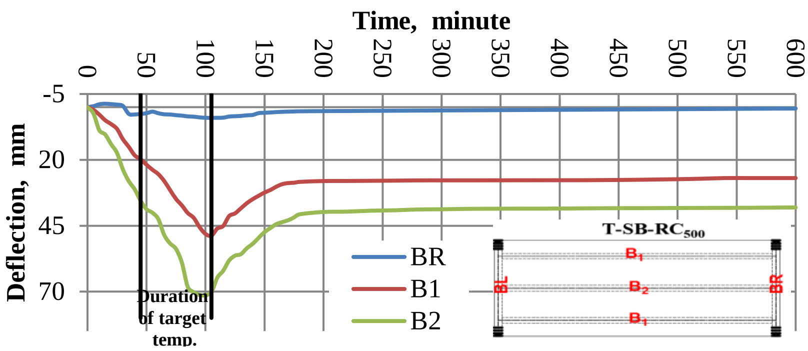

Fig. 9. Mid span deflection-time history of burned beams of composite SB-RC deck floor at temperature 500 °C.

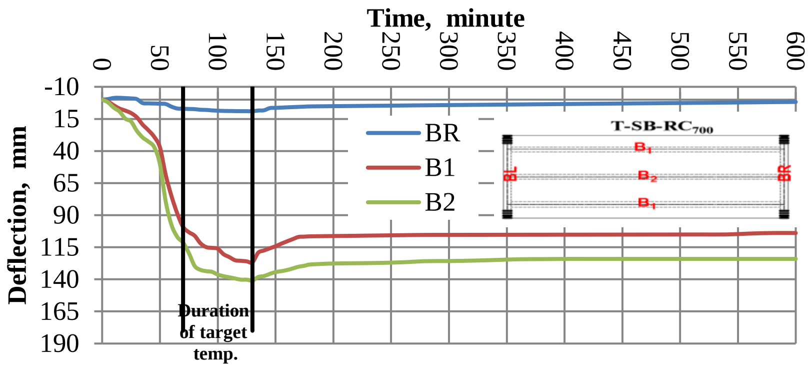

Fig. 10. Mid span deflection-time history of burned beams of composite SB-RC deck floor at temperature 700 °C.

Table 2. Mid span deflection at the end of each time period of burning and cooling stage of secondary steel beam B_2 and B_1.

Specimen No.		First period		Second period		Third period		Recovered deflection
		Time	Mid span deflection	Time	Mid span deflection	Time	Mid span deflection	mm (Recovered deflection %)
		Min.	Mm	Min.	mm	Min.	mm	
T-SB-RC_{300}	B_2	25	16.0	85	16.4	380	1.4	15.0 (92)
	B_1		6.9		8.6		0.4	8.2 (95)
T-SB-RC_{500}	B_2	45	35.2	105	71.4	500	38.3	33.1 (46)
	B_1		19.7		48.8		26.9	21.9 (45)
T-SB-RC_{700}	B_2	70	111.5	130	140.2	600	124.1	16.1 (11)
	B_1		99.1		126.6		103.8	22.8 (18)

The above figures show that the deflection of B_2 was more than that of B_1. This is due to its position and boundary end conditions, but this difference decreases between them as the burning temperature increased. In other words, increasing burning temperature leads to an increase in the deflection of B_1. Because these two beams are boundary connected by a reinforced concrete deck floor and the two end main beams, so, increasing the deterioration of the middle secondary beam B_2 has an effect on B_1.

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Figures 11 and 12 show deflection comparison of the secondary steel beams B_2 and B_1, respectively. Obviously, with increasing burning temperature, the measured deflection increased, and at the end of the burning and cooling cycle the residual deflection also increased. This reflects the amount of deterioration that happened.

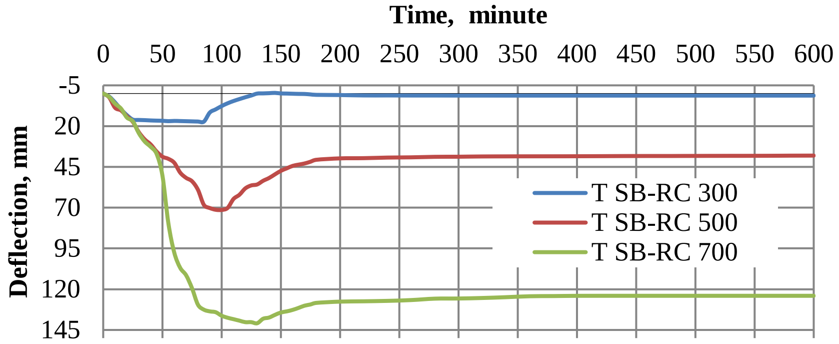

Fig. 11. Mid span deflection-time history of burned mid secondary beam B_2 of composite *SB-RC* deck floors at different temperatures.

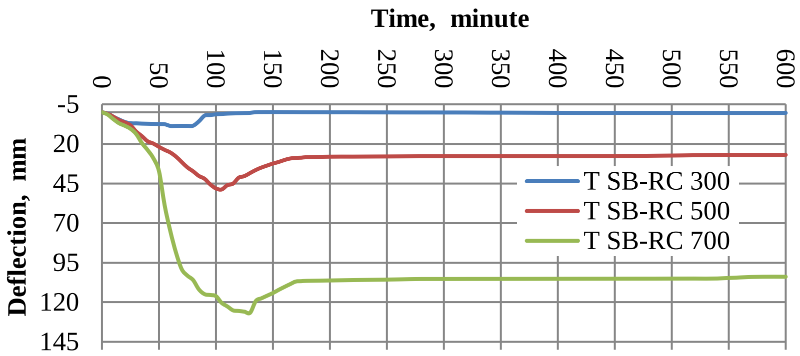

Fig. 12. Mid span deflection-time history of burned secondary beam B1 of composite SB-RC deck floors at different temperatures.

4.3. Load Application Test

At the end of the first test stage, the equivalent distributed load was removed to fix the top electrical resistance strain gauges, then the composite SB-RC deck floors were transmuted to the load test rig, the equivalent weight was returned. Hence, the residual burning deflection cannot be kept.

4.3.1. Load versus deflection

According to AISC 360, the permissible deflection limit is L/240, which means 12.5 mm. Thus, this value of deflection is used for comparison as an end service limit of the linear behaviour of composite SB-RC deck floors, as shown in Table 3.

Figures 13 and 14 reveal the effect of fire flame on the serviceability of the composite SB-RC deck floors with respect to a specimen's deflection. Obviously, as the burning temperature increased, specimen stiffness decreases, the curves become flatter, and the linear behaviour is significantly limited (marginal), i.e., deflection increases due to the defects that happen throughout the burning stage. Depending on the specified service limit (12.5 mm) the reduction in stiffness in a secondary steel beam B_2 compared with an unburned specimen was 17, 61 and 74%, while it was 25, 62 and 75 % for B_1 when they exposed to 300, 500 and 700 °C, respectively (Table 3). Also, the linear behaviour limit decreases as the burning temperature increased, due to increasing the deterioration of the test first stage. Linearity behaviour was lost when the applied load reached 65, 55, 25 and 16 kN/m² for secondary steel beam B_2, and it was 68, 56, 27 and 18 kN/m² for B_1, for the control specimen, and at burning temperature of 300, 500 and 700 °C, respectively. Secondary steel beams B_2 and B_1 had approximately the same behaviour with a significant deviation. For the unburned composite SB-RC deck floor, B_1 had a higher stiffness than B_2 by about 20%, while it was 9, 5 and 14% for the specimens exposed to 300, 500 and 700 °C, respectively.

Table 3. Load and deflection at linear service portion limit.

Specimen No.	Linear portion (Service) Load (kN/m²)		Deflection at L/240 (mm)	Burned Service load / unburned reference %
T-SB-RC R	B2	54	12.5	100
	B1	65	12.5	100
T-SB-RC300	B2	45	12.5	83
	B1	49	12.5	75
T-SB-RC500	B2	21	12.5	39
	B1	22	12.5	38
T-SB-RC700	B2	14	12.5	26
	B1	16	12.5	25

- ***Note: control Deflection according to AISC L/240 = 12.5mm***

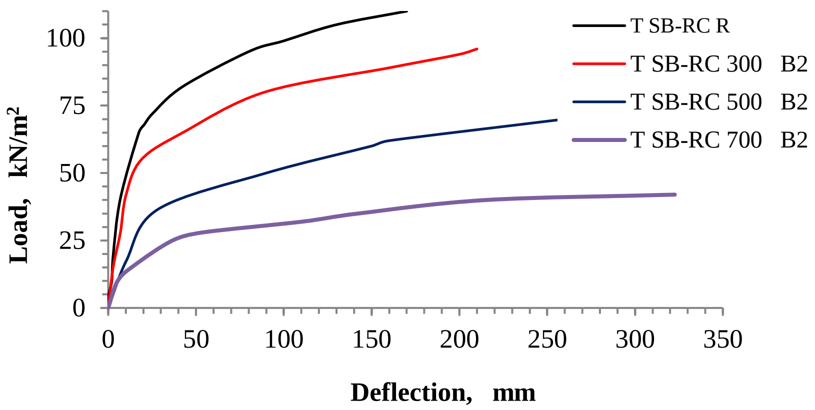

Fig. 13. Load versus mid span deflection of secondary beam B_2 of composite SB-RC deck floors at different temperatures.

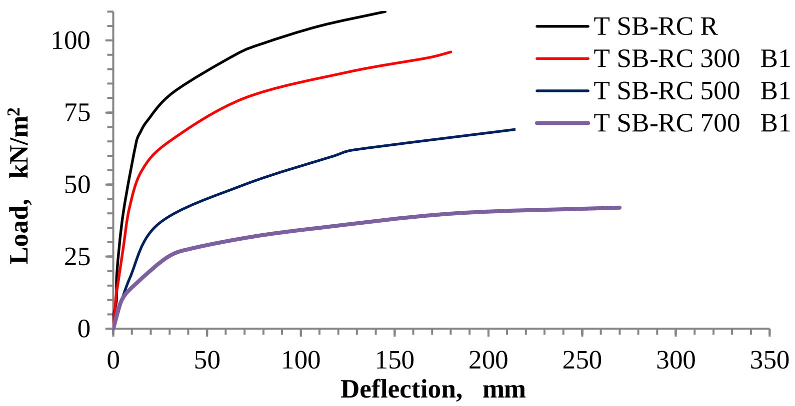

Fig. 14. Load versus mid span deflection of secondary beam B_1 of composite SB-RC deck floors at different temperatures.

4.3.2. Load versus bottom steel flange strain

During the burning stage, the thermal strain of the composite SB-RC deck floors could not be measured due to the high temperature of the fire flame.
Linear coefficient of thermal expansion (α) of structural materials ranges from 11 to 12 (x 10^{-6} / °C) for structural steel, and from 8 to 12 (x 10^{-6} / °C) for concrete. The two materials had approximated close values. Accordingly, the approximated thermal strain $\in_{therm.}$ is:

$$\in_{therm.} = \alpha \cdot \Delta t \quad (1)$$
$$\in_{therm.} = 11 \times 10^{-6} \cdot \Delta t$$

Thus, the generated thermal strain at the burning stage theoretically reached up to: 3300, 5500 and 7700 microstrain at the burning temperature of 300, 500 and 700 °C, respectively. All composite SB-RC deck floors are simply supported by using steel ball and sockets, meaning that no internal stresses are generated. Furthermore, visible permanent curvature had been observed in composite SB-RC deck floors, which were burned at 500 °C, and it was more apparent at 700 °C at the end of burning stage. This denotes that plastic deformation had taken place. This accorded with the measured residual deflection.

According to Eurocode 3: Part 1.2, the recommended modulus of elasticity reduction factors at 300, 500 and 700 °C measured by the transient-state test method, and the tested yield stresses which were found by steady-state test method are listed in Table 4. Thus, the yield strain depending on these values can be calculated. Comparing this value of strain with the measured maximum strain value of the straight line for the load strain curves, gave the percentage ratio shown in Table 4. Most of these ratios are close to the theoretically assumed yield strain values. Despite the use of two different test methods in calculating and measuring the strain, the deviation is acceptable.

Figures 15 and 16 show strain versus applied load of composite SB-RC deck floors burned at different temperatures. It can be seen that the strain increases as the burning temperature increased. The linear portion of the curve which was adopted as a reference for comparison (servisibilty limit), decreased as the burning temperature increased. Depending on the service limit of the linear curve portion which had been specified, the increase in generated strain rate compared to the unburned composite SB-RC deck floor was 150, 450 and 842 % for B2 steel beam, and 145, 466 and 933 % for B1 at a burning temperature of 300, 500 and 700 °C, respectively (Table 5). All these observations indicate that the deteriorations increase and the floor system servicibility decreases as the burning temperature increased, especially, when the composite SB-RC deck floor exposed to temperatures reaching up to 500 as well as 700 °C.

Table 4. Measured and calculated strain at the end of linear behaviour.

Specimen No.		Modulus of elasticity reduction factor	Reduced Modulus of elasticity (GPa)	Tested yield stress (MPa)	Calculated Yield strain •• (mm/mm)	Measured Strain at end of linear portion (mm/mm)	Measured / calculated strain %
T-SB-RC_R	B_2	1.0	200	360	0.0018	0.0017	94
	B_1					0.0012	67
T-SB-RC_{300}	B_2	0.80 •	160 •	328	0.00205	0.0020	98
	B_1					0.0021	103
T-SB-RC_{500}	B_2	0.60 •	120 •	252	0.0021	0.0022	105
	B_1					0.0020	95
T-SB-RC_{700}	B_2	0.13 •	26 •	76	0.0029	0.0027	93
	B_1					0.0026	90

• according to Eurocode 3: Part 1.2.
•• $\in = \sigma / E$

Table 5. Measured longitudinal bottom steel flange strain at service limit

Specimen No.		Load at service limit of (L/240) deflection (kN/m²)	Measured Strain at service limit of (L/240) deflection (mm/mm)	Generated Strain ratio of burned/unburned reference specimens %
T-SB-RC$_R$	B_2	54	0.00120	100
	B_1	65	0.00108	100
T-SB-RC$_{300}$	B_2	45	0.00150	150
	B_1	49	0.00118	145
T-SB-RC$_{500}$	B_2	21	0.00210	450
	B_1	22	0.00170	466
T-SB-RC$_{700}$	B_2	14	0.00262	842
	B_1	16	0.00248	933

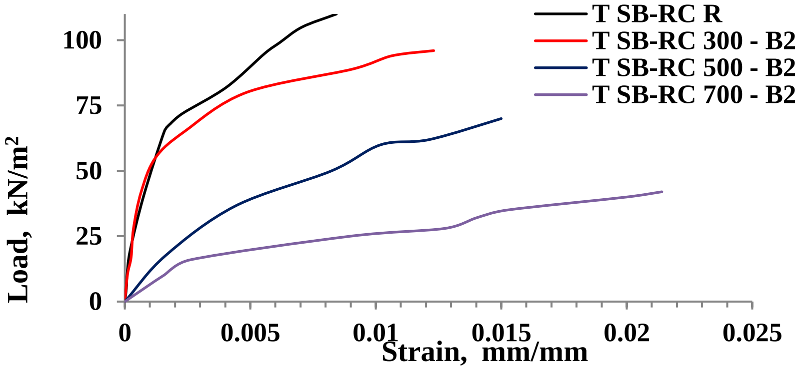

Fig. 15. Load versus bottom steel flange strain of burned specimens of B_2 beam at different temperatures.

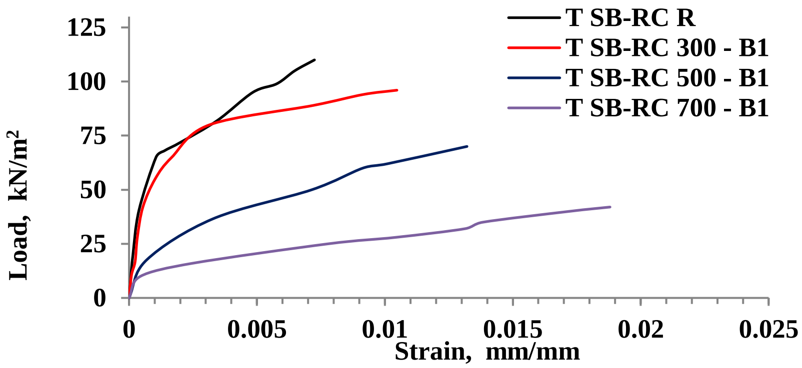

Fig. 16. Load versus bottom steel flange strain of burned specimens of B_1 beam at different temperatures

4.3.3. Load versus top concrete deck strain

Two perpendicular electrical resistance foil strain gauges were positioned at midspan, on the concrete top surface above each secondary steel beam, in the direction of secondary steel beams and transversely. Despite the exposure to high temperatures and concrete deterioration, the longitudinal and transverse top concrete deck strain were measured till about the burning temperature of 500°C was reached. Table 6 shows that the concrete strain increases as the burning temperature increased. Also, it can be seen that generating of longitudinal strain was higher than that of a transverse one, in contrast, the top concrete strains were less than the bottom steel flange. Longitudinal strain reached up to the nominal ultimate concrete strain of 3000 microstrain, in contrast with the maximum transverse strain, which was 400 and 340 microstrains above the steel beams B_2 and B_1, respectively, at a burning temperature of 300°C.

Table 6. Measured top concrete deck strain at service limit

Specimen No.	Load at service limit of (L/240) deflection (mm/mm) (kN/m²)		Longitudinal			Transvers	
			Measured strain at service limit of (L/240) deflection (mm/mm)	Generated Strain rate ratio of measured burned /unburned %	Maximum measured strain (mm/mm)	Maximum measured strain (mm/mm)	Generated strain rate ratio of burned/ unburned control specimens %
T-SB-RC$_R$	B_2	54	0.00023	-	0.0034	0.00021	-
	B_1	65	0.00017	-	0.0028	0.00015	-
T-SB-RC$_{300}$	B_2	45	0.00040	209	0.0037	0.00040	229
	B_1	49	0.00031	242	0.0030	0.00034	300
T-SB-RC$_{500}$	B_2	21	0.00069	772	0.0049	0.00033	399
	B_1	22	0.00040	696	0.0038	0.00025	498
T-SB-RC$_{700}$	B_2	14	-	-		-	-
	B_1	16	-	-		-	-

4.3.4. Ultimate load capacity and mode of failure

Residual ultimate strength is the final limit of comparison beyond the serviceability and the validation of the structural element. Table 7 shows, the residual ultimate strength capacity decreases as the burning temperature increased. For the burned composite deck floors at 300, 500 and 700 °C, it was 87, 64 and 38 % compared to unburned specimen, respectively. It can be concluded from the above results, that the composite SB-RC deck floors can carry load even when exposed to high temperatures that reached up to 500 or even 700 °C, but its serviceability was also demonstrated, by excessive deformation and elongation of the steel beams.

Failure modes of the tested composite deck floors after load test stage had been finished are summarized in Table 7. Because of the uniform equivalent of applied load, cracks cannot be specified, or crushing cannot be observed, even when top concrete strain reached the nominal ultimate value of 3000 microstrain. Failure started with apparent midspan deflection. With increasing load, the bottom steel flange reached yield stress, thereafter, excessive deflection was monitored and the composite SB-RC deck floor is unable to withstand any further applied load. Top concrete cracks and damages were observed after removing the uniform equivalent applied load.

Table 7. Load at ultimate state and mode of failure.

Specimen No.	Load (kN)	Residual strength %	Mode of failure
T-SB-RC $_R$	110	100	Concrete deck : Crushing Steel beam **B_2**: Yield Steel beam **B_1**: Yield
T-SB-RC$_{300}$	96	87	Concrete deck : Crushing Steel beam **B_2**: Yield Steel beam **B_1**: Yield
T-SB-RC$_{500}$	70	64	Concrete deck : Crushing Steel beam **B_2**: Yield Steel beam **B_1**: Yield
T-SB-RC$_{700}$	42	38	Concrete deck : Crushing Steel beam **B_2**: Yield Steel beam **B_1**: Yield

Figure 17 shows the failure of unburned composite SB-RC deck floor, which has been consisted, excessive deflection and increase in measured strain for both bottom steel flanges and top concrete. When the specimen could not resist the applied load, these loadings were removed, including the equivalent load, permanent deformation, and the formed cracks in the concrete were observed.

Figure 18 through 20 show the failure of burned composite SB-RC deck floors, which had approximately the same behaviour, but these specimens were predamaged as a result of the burning stage. Obviously, exposing to fire flame causes damages in concrete as well as steel beams, and these damages increase as the burning temperature is increased. This has affected the ultimate load resistance and the failure of these specimens. These specimens failed by yields of middle secondary steel beam B_2, followed by the two lateral ones, B_1. With increasing the applied load, excessive deflection was monitored till no additional load could be applied. Specimens' mid span deflections were proportional to the span length in two directions, due to their structural composition.

There are a number of limit states or conditions for which a structure can be considered unusable and can be considered to have failed. These are: when members or the entire structure reach yield or ultimate strength; exceed a specified maximum deflection; when fracture of members or collapse occurs.

Fig. 17. Failure of control composite SB-RC deck floor (T SB-RC$_R$).

Fig. 18. Failure of burned composite SB-RC deck floor (T SB-RC300) after loading stage.

Fig. 19. Failure of burned composite SB-RC deck floor (T SB-RC500) after loading stage.

Fig. 20. Failure of burned composite SB-RC deck floor (T SB-RC700) after loading stage.

5. Conclusions

- Because of steel have thermal conductivity is much higher than that of concrete. This difference led to a high rate of specimen deflection at the first period of rising temperature of the composite SB-RC deck floors till all specimen's parts reached to the target temperature or heat balancing, the deflection rate decreases. This phenomenon was observed at 300ºC burning temperature. While this rate of deflection continued in case of exposing to higher temperature (500 as well as 700 ºC)
- Composite SB-RC. deck floor exposed to fire flame up to 300ºC, no serious amount of permanent deflection can happen. The middle and lateral secondary steel beams are able to recover 92 and 95 % of the (16.4 and 8.6 mm) maximum deflection caused by heating. The total time needed to dissipate heat and return to ambient temperature was about 200 minutes and the residual deflection was 1.4 and 0.4 mm, respectively. The most defects were happened through the rising temperature period till reaching the specified temperature
- Burning composite SB-RC deck floor at 500 ºC for 1 hour generates mid span deflection in the middle and lateral secondary steel beams reached to 71.4 and 48.8 mm, respectively. When the specimen cooled down to ambient temperature, the residual deflection reached 38.3 and 26.9 mm, or when, the recovered deflection was 46 and 45 %, respectively. The defects were continued through the burning process till reaching the cooling period.
- Exposing a composite SB-RC deck floor to 700 ºC leads to the biggest deterioration reflected by the measured deflection of the middle and the lateral secondary steel beams, which reached 140.2 and 126.6 mm, and the recovered percentage was only 11 and 18 %.
- Loading the preburned composite SB-RC deck floor at 300, 500 and 70 ºC, gives a decrease in specimens' stiffness compared to the unburned ones, by about 17, 61 and 74 % for the middle secondary steel beam and 25, 62 and 75 % for the lateral ones, respectively. Means, as the burning temperature increased initial stiffness decreases.
- The reduction in service limit depending on the maximum linearity behaviour of the load-deflection curves of burned to unburned composite SB-RC deck floors were, 15, 62 and 75 % for beam $\mathbf{B_2}$ and it was 18, 60, and 74 % for $\mathbf{B_1}$ specimens at burning temperature of 300, 500 and 700 °C, respectively. Indicates that, as the burning temperature increased the linearity behaviour of load-deflection decreases or the curves be more flatten.
- The residual ultimate strength capacity decreases as the burning temperature increased. For the burned composite deck floors at 300, 500 and 700 °C, it was 87, 64 and 38 % compared to unburned specimen, respectively.
- Excessive deflection was monitored with yielding steel beams and concrete deterioration, but the total collapse of the burned composite SB-RC deck floors was not observed, and can carry load even when exposed to high temperatures that reached up to 500 or even 700 °C.

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