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***Research Paper***

# Elevated Temperature Effects on the Behavior of One-Way Fibrous Reinforced Concrete Slabs

**Dr. Mazin B. Abdul-Rahman[1]*, Dr. Alya'a A. Al-attar[2], Amenah M. Younus[3]**

[1] *Civil Engineering Department, Tikrit University, Salahuddin, Iraq*
[2] *Technical College of Kirkuk, Kirkuk, Iraq*
[3] *Civil Engineering Department, Tikrit University, Salahuddin, Iraq*
**Corresponding author E-mail: dr.mazinburhan@tu.edu.iq*

**Abstract**

In this research, the effect of elevated temperature on the flexural behavior of one-way reinforced concrete slabs under service static loads contain different volume fraction (0.25% , 0.75% and 1.25%) of steel fibers and different addition ratios (15%, 20% and 25%) of fly ash in addition to the reference slabs with not any additives was studied. For this purpose, thirty cylinders (150 *300)mm , thirty prisms (100 * 100 * 500)mm and forty one-way slabs (900 * 350 * 70) mm were cast and tested. The one-way tested slabs were divided into two groups. The first group (of twenty slabs) were tested to determine the ultimate flexural strength under static loads at normal temperature. While the second group (of twenty slabs) were tested to determine the flexural behavior of slabs under static service loads at elevated temperature (using burning furnace). In this test, the samples are exposed to rising temperature reached 850℃. From these tests, the relationships between the load and mid-span deflection as well as the relations between the fire-time and mid-span deflection are measured. The results showed that the addition of steel fibers and fly ash particles will enhance the flexural behavior of concrete slabs. The highest increase in ultimate load compared to the reference slab was (28.31%) at the volume ratio 1.25% of the steel fibers and 25% of the fly ash at normal temperatures , And the rate of increase of the deflection with fire time was the lowest increase rate is 14.1% at the volume of 1.25% of steel fibers and the proportion of weight 20% of fly ash at high temperature.

***Keywords***: *Elevated Temperature, Flexural Behavior, One way slabs.*

## 1. Introduction

Structural elements are exposed during the period of their investment to different working conditions and may be different from the design considerations of these elements, which leads to a negative effect on the mechanical and physical properties, and the effect of high temperatures resulting from several factors such as fire and other phenomena that should be given special importance because of its effect on toughness and the durability of concrete structures. As concrete is an essential element of construction, its behavior and characteristics during exposure to high temperatures get a great deal of attention. In general, the concrete exhibits good behavior while exposed to The heat is high because it is low heat conductivity and it is a good heat insulator for reinforcing bars, but there is an essential problem caused by high temperatures, which is the separation of concrete blocks from the body of the concrete element, which is called , spalling , which leads to decrease in the thickness of the concrete cover of the reinforcing steel. These steel bars become directly exposed to the high temperature, which reduces the concrete sample's ability to resist the tensile strength and increase the steel bars ductility. This may cause the direct collapse in concrete installations (Nassar,2011). Concrete shall be acceptable to fire resisting compared with other materials such as steel and wood ,but there is extensive damage or even catastrophic failure can cause concrete structures at high temperatures. However, fire resistance, concrete strength and the rate of force gained can be improved with the addition of Pozzolanic materials (Soni,2014). Fly ash is one of the most commonly used Pozzolanic materials in the world. Fire resistance can also be improved by short intermittent fibers, which are randomly distributed within the cement mix to improve the mechanical properties of concrete in all directions (Al-Bayati,2012). So as to prevent spalling of concrete components at high temperatures.

## 2. Literature Review

In 2011, Almottiri conducted a practical study to investigate the mechanical behavior of fly ash concrete reinforced with steel fibers in compression and flexural by conducting standard tests on samples. According to its results, the use of steel fibers in fly ash containing concrete will improves its mechanical properties, especially in tensile and flexural strength , and that increasing fly ash to 30% and steel fibers to 1.5% in concrete enhances tensile strength flexural strength as well as compressive strength. The researcher recommended using fly ash concrete reinforced with iron fibers as an alternative to conventional reinforced concrete.

In 2013, Ghazi presented a practical study on the effect of adding steel fibers on the compressive strength of concrete exposed to high temperatures ranging from 100 to 700 ° C . The researcher conducted two types of tests: one for nondestructive test , an ultrasonic pulse velocity (UPV) and the other one destructive by using 48 cubes (half reinforced by 1% volume steel fibers and other models without steel fibers) to different temperature levels (100,200,300,400,500,600,700)℃ . Both tests showed, the addition of steel fibers increases the residual compressive strength at

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all grade levels, with the highest increase (56.9%) of those not reinforced by steel fibers.

In 2015, Sood conducted a practical study on the effect of adding fly ash on normal concrete using three replacement ratios (20%, 40%, 60%) of cement weight. The optimum replacement content was found to be 20% of the cement content. Its results showed that the maximum compressive resistance was recorded at the lowest content of fly ash by 20% compared to reference concrete at all ages (56,28) days, therefor he used replacement ratio (15% to 25%) of cement content in fly ash for the casting of one-way concrete slabs. It was concluded that the flexure resistance of fly-ash concrete continued to increase with increased fly ash replacement rates and also in all ages.

In 2015, Jamerana and others conducted a practical study to investigate the behavior of mechanical properties of reinforced concrete under the effect of high temperatures. Two types of fiber (steel fibers and polypropylene fibers) were mixed with different percentages for each type but with a fixed volume ratio (1.5%) of the size of the concrete. And then carried out mechanical tests at different temperatures (27,200,400)℃ . It was concluded that the addition of steel fibers to the concrete mixture reduces the effects of deterioration in concrete due to fire. The addition of steel fibers has had a greater effect on the enhancement of the mechanical properties of concrete, in addition to its role in preventing the growth of cracks in the concrete.

In 2016, Ramesh and others conducted a practical study to investigate the performance of high fly ash volume (HVFA) in concrete when exposed to high temperatures of 800 ℃ and for specific time intervals of 200 ℃ and for three hours in a test program that includes replacing cement with fly ash from 30 % To 50%, and temperatures from 27 ℃ to 800 ℃ at specified intervals of 200 ℃ and for 3 hours. The results of the test showed that the addition of fly ash mixture achieved a higher percentage of residual compressive strength points at all temperatures compared to normal concrete. All concrete mixtures showed an increase in resistance to 400 ℃ and decreased after 400 ℃ . Also a gradual decrease in weight loss ratio with an increase in fly ash ratios for all temperatures.

In 2017, Al-Bayati conducted a practical and theoretical study of the behavior of Reactive Powder Concrete (RPC) in bending under the effect of service loads and fire conditions using PPF and SF fibers as well as hybrid fibers (50% polypropylene fibers + 50% steel fibers) of different volume fractions (0.25%, 0.75%, 1.25%) and compared with the reference beam (without fibers) . Samples of beams were loaded with static service loads, and then the beams were exposed to fire from the bottom and sides for 120 minutes according to the standard curve of temperature changes according to time (ASTM E 119). According to the results of the researcher, the full concrete cover of the reference beam has been spalling at high temperatures, but this spalling is reduced by increasing the volume ratios of polypropylene fibers and hybrid fibers and preventing them permanently at the high ratios of these fibers. While the spalling is reduced for different volume fractions of steel fibers but don't prevent it completely. The RPC beams reinforced by hybrid fibers showed higher fire resistance with less deflection compared with the fiber reinforced polypropylene and fiber reinforced beams.

## 3. Aim of Study

The objective of this research is to study the behavior of one-way fibrous concrete slabs exposed to high temperatures when it loaded with static service loads. The study also aims to study the effect of steel fiber added to concrete on the behavior of these slabs (maximum load, deflection, spalling) under the influence of high temperatures.

## 4. Experimental Program

In the current study, three volume fractions (0.25%, 0.75%, 1.25%) of steel fibers were used, in addition to the use of three weight ratios (15%, 20%, 25%) of fly ash, which is added to the mixture as a partial replacement of cement weight, as well as of use the fixed of water to cement ratio (W/Cm = 0.4) for all concrete mixtures. In addition, a slump ranging between (50-75) mm was adopted, in addition to the use and increase of the quantity of the superplasticizer added to the concrete mixtures as needed to obtain the required workability, as shown in Table 1.

## 5. Discussion of Results

### Mechanical Properties of Hardened Concrete

#### a. Compressive Strength( ($f'_c$)

Compressive strength in concrete is one of the most important mechanical properties of concrete in most structural applications. In the present study, the compressive strength was tasted at 28 days for all concrete mixtures by taking the rate of three cylinders for each mixture, as shown in Table 1.

**Table 1:** rate of compressive strength ($f'_c$) for all concrete mixtures

| Group No. | Mix No. | SF % | FA% | W/Cm | SP% | Slump (mm) | Compressive strength (28) day ($f'_c$) MPa | | | Increasing % of $f'_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Ref. | M1 | 0 | 0 | 0.4 | 0 | 75 | 34.58 | — | | |
| G1 | M2 | 0.25 | ١5 | 0.4 | 1 | 57 | 42.32 | 22.38 | | |
| | M3 | 0.25 | ٢0 | 0.4 | 0.98 | 61 | 39.58 | 14.50 | | |
| | M4 | 0.25 | ٢5 | 0.4 | 0.98 | 73 | 3٩.47 | 14.14 | | |
| G2 | M5 | 0.75 | ١5 | 0.4 | 1.04 | ٦٥ | 47.52 | 37.42 | | |
| | M6 | 0.75 | ٢0 | 0.4 | 1.02 | ٧١ | 42.68 | 23.42 | | |
| | M7 | 0.75 | ٢5 | 0.4 | 1.01 | ٦7 | 49.39 | 42.83 | | |
| G3 | M8 | 1.25 | ١5 | 0.4 | 1.22 | 59 | 55.88 | 61.60 | | |
| | M9 | 1.25 | ٢0 | 0.4 | 1.2 | ٦1 | 46.28 | 33.83 | | |
| | M10 | 1.25 | ٢5 | 0.4 | 1.٢ | 65 | 49.93 | 44.39 | | |

The results showed that the concrete mix (M8) containing (1.25) of steel fibers and (15%) of fly ash recorded the highest compressive strength for all mixtures with an increase of (61.6%) compared to the reference mixture (M1) , This increase is due to the regular distribution of fiber within the concrete textures , which makes it more cohesive and hard to resist cracking in the tensile area and resist the resulting side strains , as well as the good reaction of fly ash with calcium hydroxide resulting from the cement

hydration process which resulted in denser , stronger and less permeable concrete .

In concrete mixtures containing different volume ratios of steel fibers and different weight ratios of fly ash, we observe an increased reduction in compressive strength by increasing fly ash content to the same ratio of fibers for all mixtures except M7 and M10. This is due to the slow Pozzolan reaction which causes To delay the acquisition of resistance in the early ages but give exceptional results at the long extent, while offset by a significant increase in compressive strength by increasing the volume ratios of steel fibers in the concrete mix because of the fact that the coefficient of elasticity of steel fibers is higher than the coefficient for the elasticity of concrete (Adanagouda,2015), (Al-Bayati,2012) these results correspond to the results of other researchers.

### b. Modulus of Rupture ($f_r$)

Modulus of rupture test (flexural strength) is the important tests of the hardened concrete. It shows the resistance of the concrete to the bending without reinforcing steel. It is of low value because of the low resistance of the concrete to the tensile as mentioned above, as it is also affected by the quality and quantity of materials involved in the production of concrete . The results of the Modulus of rupture test for all concrete mixtures at 28 days are shown in Table 2.

**Table 2**: rate of flexural strength ($f_r$) for all concrete mixtures

| Group No. | Mix No. | SF % | FA % | W/Cm | SP % | Flexural strength (28) day ($f_r$) MPa | Increasing % of $f_r$ |
|---|---|---|---|---|---|---|---|
| **Ref.** | M1 | 0 | 0 | 0.4 | 0 | 4.49 | — |
| **G1** | M2 | 0.25 | ١5 | 0.4 | 1 | 5.00 | 11.36 |
| | M3 | 0.25 | ٢0 | 0.4 | 0.98 | 5.76 | 28.29 |
| | M4 | 0.25 | ٢5 | 0.4 | 0.98 | 5.75 | 28.06 |
| **G2** | M5 | 0.75 | ١5 | 0.4 | 1.04 | 7.09 | 57.91 |
| | M6 | 0.75 | ٢0 | 0.4 | 1.02 | 7.52 | 67.48 |
| | M7 | 0.75 | ٢5 | 0.4 | 1.01 | 7.61 | 69.49 |
| **G3** | M8 | 1.25 | ١5 | 0.4 | 1.22 | 7. 29 | 62.36 |
| | M9 | 1.25 | ٢0 | 0.4 | 1.2 | 7.88 | 75.50 |
| | M10 | 1.25 | ٢5 | 0.4 | 1.٢ | 8.03 | 78.84 |

From the above, table we observe the increase of the flexural resistance of the concrete by increasing the weight ratios of fly ash and increasing the volume ratios of steel fibers. This is due to the reaction of fly ash particles with the calcium hydroxide resulting from cement hydration process form additional calcium silicate during the reaction process, thus increase the strength of bonding between the concrete and steel fibers also improves the flexural resistance by adding steel fiber which produces a denser ,less permeability and high durability concrete ,as well as ,the high flexibility coefficient of steel fibers (higher than the normal concrete elasticity coefficient) which makes them contribute with the concrete mixture in resistance of tensile stresses, delay the appearance of bending cracks , improves ductility and resistance to bending. This finding is corresponding with other researchers (Al-Bayati, 2012), (Almottiri, 2011).

### c. Flexural Behavior of One-Way Reinforced Concrete Slabs

The main objective of the research is to investigate the behavior of one-way reinforced concrete slabs, which contains fly-ash particles and reinforced with steel fibers ,in the structural state ,under the static load in the normal temperatures, by the linear load In the middle of each slab and for all concrete slabs of (S2 to S10) and comparing them with the reference concrete slab (S1), as well as investigating the effect of high elevated temperature with static service loads representing 50% of the ultimate load of failure on behavior for the same concrete slabs mentioned above (Abassi,2006) . This behavior was studied practically on (40) concrete slabs with dimensions of (70 × 350 × 900) mm, at 28 days and with the same reinforcement for all slabs. Figure (1) shows the details of the reinforced concrete slab. The results of the following tests are based on the curve (load - deflection) at normal temperatures, as well as the curve (deflection - fire time) in the high elevated temperature at the middle of the concrete slab space.

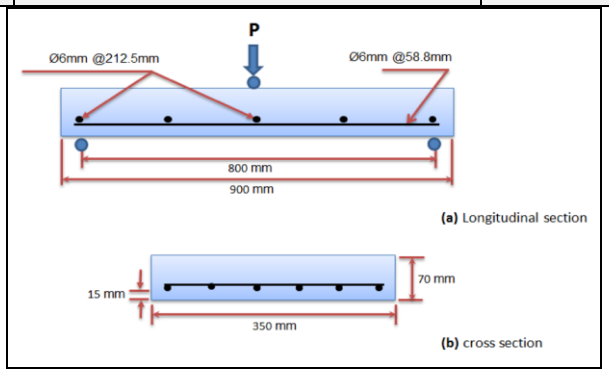



**Fig. 1**: The details of reinforced concrete slab

## I. Flexural Behavior of Concrete Slabs at Normal Temperatures

Figure (٢) shows the load-deflection curve of the reference concrete slab. Where the curve is linear up to the appearance of the first crack , then begins the post-crack phase begins where the curve is approximately linear and less inclined than the first part, because the loss of part of the slab stiffness due to cracks, then the post-crack phase ends at the yielding point of steel reinforcement .Then begins the new stage also of the post yielding phase, which is increases the deflection significantly, until reaching the ultimate load of ($P_u$=22.1 kN) where the failure of the concrete slab completely fails.

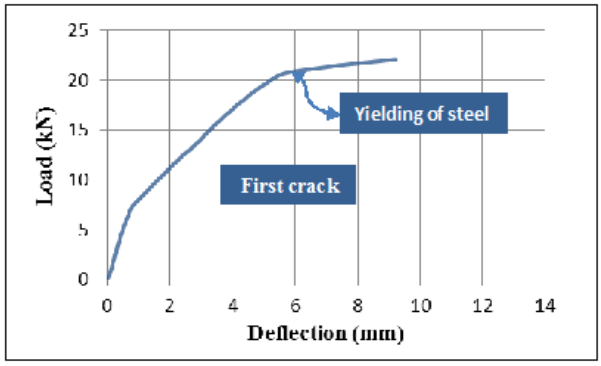



**Fig. 2:** Load-deflection curve of the reference reinforced concrete slab

The effect of addition of steel fibers with different volume rates (0.25%, 0.75% and 1.25%) is illustrated by shapes (3), (4) and (5) on the load-deflection curve of reinforced concrete slabs containing fly ash additives (15%, 20%, 25%) , compared with the reference slab (without additives) . We note that the addition of these fibers in different volume ratios have a significant impact on the improvement of compressive strength and the coefficient of elasticity and flexural strength of concrete.

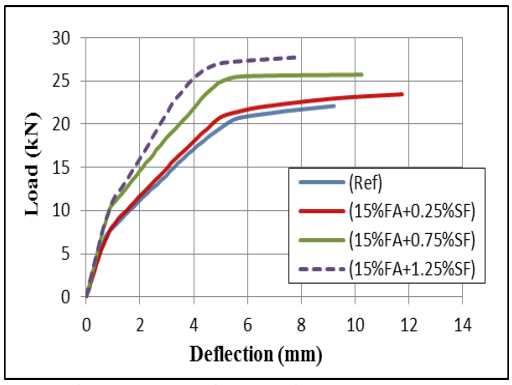



**Fig. 3:** Load-deflection curve of the reinforced concrete slabs with a volume fractions of (0.25%, 0.75%, 1.25%) of steel fibers and with a weight ratio of 15% of fly ash

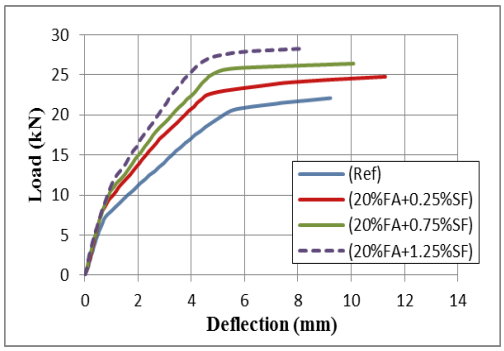



**Fig. 4:** Load-deflection curve of the reinforced concrete slabs with a volume fractions of (0.25%, 0.75%, 1.25%) of steel fibers and with a weight ratio of 20% of fly ash

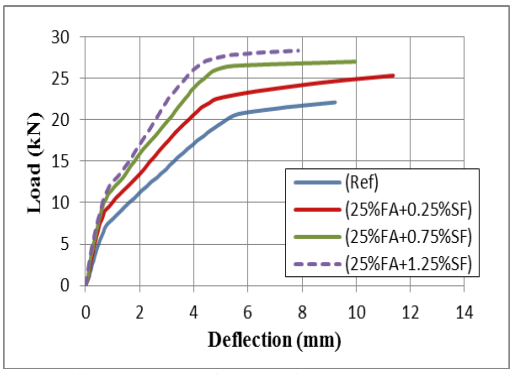



**Fig. 5:** Load-deflection curve of the reinforced concrete slabs with a volume fractions of (0.25%, 0.75%, and 1.25% of steel fibers and with a weight ratio of 25% of fly ash

From the curves above we note the increase in the load in which the first crack occurs with a decrease in the deflection by increasing the volume ratio of the steel fiber added because of the good bonding of these fibers with the concrete mix and thus contribute to resist compressive and tension stresses before any cracks in the concrete, as well as reduce the growth capillaries cracks as it arises .We also note that the addition of fly ash particles in different weight ratios has little effect on the load- deflection curve at all loading stages, in the pre-cracking zone and in the post-cracking zone. Although increasing in the weight ratios of fly ash reduces compressive resistance, it has little effect on improving flexural strength in concrete for all weight ratios used in the present study. This effect is due to increased density of concrete and fewer gaps generated as well as increased bonding between steel fibers and bonding material containing fly ash particles. These results correspond to the results of other researchers (Al-Bayati,2012).

## II. Flexural Behavior of Concrete Slabs at High Temperatures

High temperatures are the effect on various properties of concrete significantly. The increase in temperature causes significant changes in the chemical structure, microstructure and moisture content of concrete. Pore pressure develops in concrete exposed to high temperatures due to heating and may reach This pressure to the value greater than tension force , which is causing the separation of concrete layers or blocks from the body of the concrete element, which is called spalling. This leads to a decrease in the thickness of the concrete cover and thus the steel bars are exposed directly to the high temperature, which reduces the ability of the concrete sample on resist tensile forces and increases their brittleness, all this may cause directly in collapses in concrete structures. In addition, the thermal variation (in the slabs or beams) between the top and bottom causes additional deflection due to the temperature, thus increasing the deflection in the presence of the static load, and the high temperatures will result in the loss of the elasticity coefficient and in both resistors (yield and ultimate strengths) (Nassar,2011) , (Khan, 2013) and (Sangluaia,2013) .These results correspond to the results of other researchers. Figure (6) shows the deflection-fire time curve of the reference concrete slab when exposed to high temperatures due to heating and load stabilization (50% of the ultimate load) on the concrete slab prior to the start of the heating process according to ASTM E119.

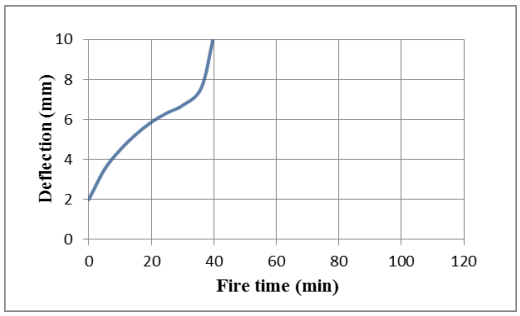



**Fig. 6:** Fire time-deflection curve of the reference reinforced concrete slab

The effect of adding steel fibers with different volume fractions of (0.25%, 0.75%, 1.25%) on the fire time-deflection curve of reinforced concrete slabs containing different weight ratios of (15%, 20% 25) of fly ash additives compared with the reference slab (without additives), is shown in Figures (7) , (8) and (9). The addition of these fibers in different volume fractions has a positive effect on the fire time-deflection at all levels of temperature and thus increase the fire resistance, this is because that the addition of these fibers to the concrete increases the resistance of compressive and tensile residual strength for all elevated temperatures, as well as reducing pore pressure due to its effectiveness in improving compressive and tensile strength in concrete, which helps to resist the accumulation of vapor pressure under high temperatures and thus prevent the occurrence of spalling . In addition, the steel fibers have a high thermal conductivity as compared with the concrete, and thus contribute in reducing thermal gradient in the slab cross-section which leads to reduce the internal thermal stresses, thus maintaining the concrete cover of the concrete. Which helps protect the reinforcing steel from direct exposure to heat and thus reduces the damage that affects the durability and tensile strength of steel and concrete , these results correspond to the results of other researchers (Jamerana,2015), (Nair,2016), (Petrus,2016) and (Al-Bayati,2017) .

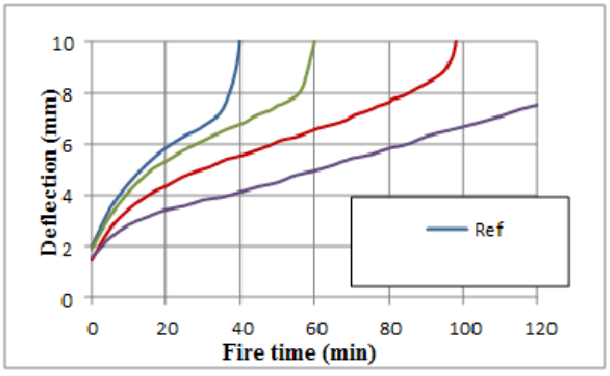



**Fig. 7:** Fire time-deflection curve of the reinforced concrete slabs with a volume fractions of (0.25%, 0.75%, 1.25%)of steel fibers and with a weight ratio of 15% of fly ash

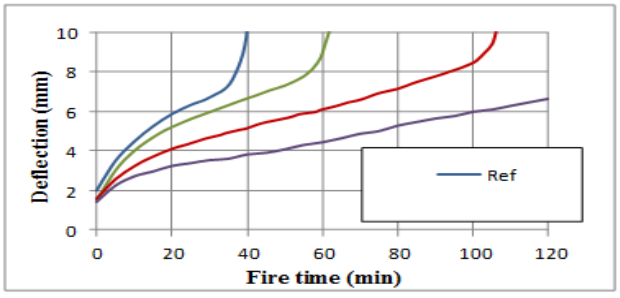



**Fig. 8:** Fire time-deflection curve of the reinforced concrete slabs with a volume fractions of (0.25%, 0.75%, 1.25%) of steel fibers and with a weight ratio of 20% of fly ash

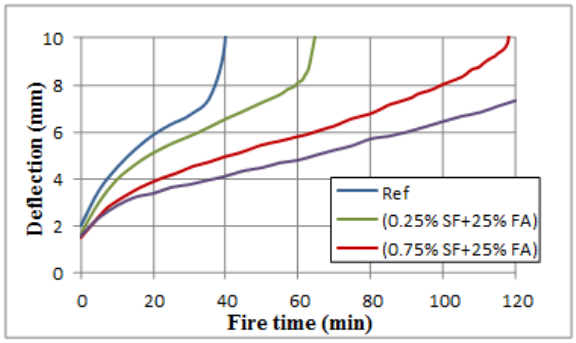



**Fig. 9:** Fire time-deflection curve of the reinforced concrete slabs with a volume fractions of (0.25%, 0.75%, 1.25%)of steel fibers and with a weight ratio of 25% of fly ash

From the curves above, we observe the increase in the fire resistance of the concrete by the increase in the volume fraction of the steel fibers (Kadhum,2006), (Al-Bayati,2017) . It is also observed that the addition of fly ash particles in different weight ratios has a significant positive effect on the fire time-deflection curve at all temperatures. This may be due to the thermal conductivity of concrete increases with the addition of fly ash due to the increased density of concrete due to dense ash structure , Thus contributing to reducing the thermal gradient between the top and bottom of the slab, which leads to reducing internal thermal stresses.

## 6. Conclusions

The replacement of fly ash particles with different weight ratios of (15%, 20%, 25%) of the cement improves the compression resistance for all the weight ratios compared to the reference concrete (without ash), but the increased replacement rates of fly ash caused A reduction in compressive strength of concrete cylinders. The addition of steel fibers performs a significant improvement in the resistance of compression of concrete cylinders, and this improvement is increased by increasing the volume ratios of steel fibers. The flexural strength of the concrete is increased by increasing the weight and volume ratios of fly ash particles and steel fibers, respectively. Increasing the weight ratios of fly ash particles and volume fractions of steel fibers led to increasing the ultimate load in reinforced concrete slabs and delayed appearance of initial cracks in reinforced concrete slabs during flexure testing. When concrete slabs were exposed to heat as a result of the fire, high temperatures led to the cracking and separation of a part of the concrete cover in the reference slab (without additive), but the addition of fly ash particles and steel fibers reduced and approximately prevented spalling in the other concrete slabs. Concrete slabs containing fly ash and steel fibers showed higher fire resistance and less deflection than the reference slab.

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