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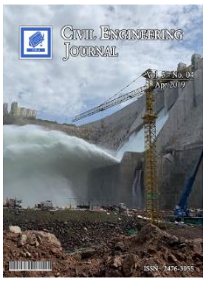

Flexural Behavior of Unbounded Pre-stressed Beams Modified With Carbon Nanotubes under Elevated Temperature

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Abstract

Since fire is one of the common reasons for rehabilitation and reconstructions during the service life of a building, it is necessary to assess the elements structural and technical conditions. The objective of the present paper is to investigate the flexural behavior in bending for unbounded full pre-stressed beams with and without the incorporation of carbon nanotubes (CNTs) under the exposure to elevated temperature in comparison with non-pre-stressed beams. The test Method was divided into two major stages where the principal stage's goal was considering the flexural behavior of fully and non-prestressed concrete beams containing CNT of 0 and 0.04% as cement replacement at ambient temperature. In the second stage, a typical group of beams was prepared and the flexural behavior was explored under the exposure to temperature of 400ºC, for 120 minutes. The major findings upon monitoring the failure mechanisms, ultimate load capacity, and deflection at critical sections, was that the CNT had shown a significant impact on the behavior and extreme resistance of fully and non-prestressed normal concrete. With CNT beams also exhibited higher imperviousness to high-temperature than that of the normal beams. Finally the significant Improvement was that the ultimate load of the non-pre-stressed beam with the presence of the CNT at the lower 50mm in the tension zone showed a gain of 13%, while the ultimate load of the fully pre-stressed beam with the presence of the CNT at the lower 50mm in the tension zone showed a gain of 21% as compared to the same beam without CNT, respectively. For the non-pre-stressed beams, the load capacity of the beam with CNT after exposure had a similar load capacity as the beam without CNT before exposure to high temperature.

Keywords: Full Pre-Stressed Beam; Carbon Nanotubes; Elevated Temperature; Unbounded Pre-Stressed; Crack Pattern.

1. Introduction

In recent years, there is an expanded utilization of pre-stressed concrete (PC) elements in buildings, bridges, towers, pressure vessels and offshore structures. In numerous structures, the architectural requirements prescribe the incorporation of a long span and slender elements in which the PC is rendered the most achievable design alternative, since it allows for the rapid erection of economical and sustainable buildings.

The use of pre-stressed concrete provides advantages over non-prestressed reinforced concrete. These advantages as that the pre-stressing permits decreased beam depths to be accomplished for corresponding design strengths. The

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lighter structure allows the use of longer spanning elements with a high strength to weight characteristics. In the event that the member is suspected to cracks, overload, which may develop, prestressed elements will lead to the removal of the overload. The pre-stressing allows a more efficient procedure of steel and enables the economic use of high strength concrete and high tensile steels. Many researchers had studied the comparison between fully, and partially pre-stressing elements. The comparison demonstrated that the fully pre-stressing elements are characterized with more ductility, lower cost, and decreased camber, cracking at end zones, as well as crack width than the non prestressed [1-3]. Moreover recent research also studied applications like investigating the flexural behavior of prestressed concrete segmental beams as well as the deflection of un-bonded partially prestressed concrete beams [4-7].

The fire has a very significant effect on the flexural behavior of the concrete elements, especially pre-stressed concrete beams. During fire exposure, the internal water pressure under temperature gradients generates high localized stresses, which may cause concrete spalling, collapse of the elements and damages. In general, calculation of the fire resistance capacity of concrete is difficult because not only the concrete is a combined material with several components having thermal characteristics differently, but it has also properties that depend on porosity, and moisture such as density which affects concrete thermal properties [8]. It has been previously reported by [9] that the exposure to fire reduced the flexural capacity of the partially and fully pre-stressed beams. This reduction in the flexural capacity points out to the sensitivity of concrete with high strength as the one used in pre-stressed elements to fire due to the low permeability of high strength concrete.

Recently the addition of carbon Nanotubes to concrete has been studied. For concrete, CNT percentages 0.003%, 0.006%, and 0.01% (by cement weight) were added to concrete and its effect on the compressive strength was studied at curing time 90 days, the results reached a significant gains as reported by [10-12]. The gain in compressive strength was 17.65% with regards to the control batch. Crack bridging has been readily observed in CNT cementitious composites and accounts for another essential advantage of incorporating CNTs into concrete, since concrete by itself is a brittle material and increasing its resistance to cracking via CNT bridging of voids and cracks will enhance its durability. The connecting effect of CNTs also increases flexural strength by increasing load transfer under stress. Fiber reinforcements have already been widely studied and used in concrete as a way to resist crack propagation and increase flexural strength [13], but CNTs move the connecting effect from the macro- and micro- to the nano-scopic level and have the potential to act as fillers of voids and pores [14], thereby resulting in a more intrusive and efficient kind of reinforcement which withholds crack propagation at the very onset, whereas microfibers could only delay crack development but could not inhibit it once it had [15], compared the performance of CNT- versus carbon-fiber-reinforced mortars and found that, while both reinforcing materials cause a similar increase in flexural strength, the latter decreased the compressive strength and increased the porosity. Moreover, and although there is not enough literature about the effect of CNT on the fire resistance of concrete, [16], studied the effect of thermal exposure on CNT reinforced concrete elements, and the results revealed that the further hydration process was impeded by the addition of CNT and the strength was improved greatly because of the CNT presence that works as channels for the release of high-pressure steam to reduce the crack growth due to the steam.

As concrete becomes warmer, the volume of the aggregate increases whiles the hardened cement paste surrounding the aggregate shrinks. Due to these counter-acting processes, the bond between the cement matrix and aggregate (known as the transition zone) becomes the weakest point in the composite and the concrete then suffers damage by cracking [17-19]. The advantages of carbon nanotubes are: crack prevention and mechanical durability in concrete, thermal properties and enhanced mechanical in ceramics and real-time structural health monitoring capacity [20].

The volume changes in the cement matrix and aggregate are a result of a combination of physicochemical changes, which occur in concrete during thermal loading, this raises the advantage of using CNT particles in order to make use of their flexural and tensile enhancements to concrete properties. These reported advantages of carbon nanotubes could be summarized as: crack prevention and flexural durability in concrete, thermal properties and enhanced flexural properties in ceramics and real-time structural health monitoring capacity could also help in enhancing the flexural capacity of the pre-stressing beams, and as such increasing the advantage of using them.

This required a research work to investigate the effectiveness of incorporating carbon nano tubes particles into fully, and non-pre-stressed concrete beams in enhancing their structural behavior and increasing their flexural capacities as well as enhancing their resistance to the exposure to elevated temperature at the level of 400ºC, for 120 minutes duration. To study ductility of simply supported beams under elevated temperature, Modes of failure, ultimate load capacity carrying, and deflection at critical sections. The cracking flexural behavior of fully and non-prestressed simply supported concrete beams was presented.

2. Methodology

The methodology implemented in this research is based on an experimental program. The experimental program was designed for unbounded post tension prestressed and, non-prestressed concrete simply supported beams. All specimens of the experimental work were tested under static vertical load in the laboratories of National Research

Centre (NRC), and Housing and Building National Research Center (HBRC) of Egypt. Mechanical descriptions of the used materials and details of the beam geometry, materials, casting and testing methodology are described in the next part. The parameters were studied the pre-stressing level (fully or non-prestressed), the (CNT) ratio (0, and 0.04 %), and the elevated temperature level; ambient or 400ºC, for 120 minutes duration.

3. Experimental Program

3.1. Description of Test Specimens

The experimental work consisted of testing a total of eight simply supported post tension concrete beams under flexural loading which were in two groups the experimental programs was divided. In the first group, the objective was studying the flexural performance of four fully, and non-prestressed concrete beams simply supported with (0, and 0.04 %) ratios of (CNT) as control beams. In the second group, the residual flexural performance of four fully, and non-prestressed concrete beams simply supported with (0, and 0.04 %) ratios of carbon nanotubes were loaded after the elevated temperature at 400 °C for 120 minutes duration.

All beams had the same an overall width, depth and length dimensions of 150 mm, 300 mm and 1250 mm respectively, and shear reinforcement. The stirrups were 8mm diameter bars every 170 mm to prevent the possibility of shear failure. The beams were simply supported with a clear span of 1050mm. The pre-stressing tendon had a straight profile shape with a concrete cover of 50 mm. The one strand with diameter 12.7 mm was the only lower reinforcement for the fully post tension beams as shown in Figure 1, whereas two 12 mm diameter bars where the main reinforcement for the non-pre-stressed beams as shown in Figure 2. The non-prestressed, and fully prestressed concrete beams with 0.04% (CNT) ratio added to the concrete casted in the lower 50 mm from the beams depth only, while the rest of the depth was cast with normal concrete as shown in Figures 3 and 4 and The specific details of each specimen are described in Table1.

Table 1. Details of tested beams

Beam	AS	AŚ	Elevated
F.P	_	2Φ10	NE
F.P-CNT	_	2Φ10	NE
R.C	2Φ12	2Φ10	NE
R.C- CNT	2Φ12	2Φ10	E
F.P-400	_	2Φ10	NE
F.P-CNT-400	_	2Φ10	E
R.C-400	2Φ12	2Φ10	NE
R.C- CNT-400	2Φ12	2Φ10	E

The specimens designate were in the form (RC, or FP- CNT - NE or E). RC or FP refers to the non- prestressed, and fully prestressed concrete beams respectively, (CNT) refers to the carbon nano-tube, and (E or NE) refers to the fire condition (elevated or not elevated) temperature respectively. For the anchorage zone of the tested post tension concrete beam, a steel plate dimensions of 120 mm, 120 mm, and 20 mm thickness was supported with the anchorage zone reinforcement, as shown in Figure 5.

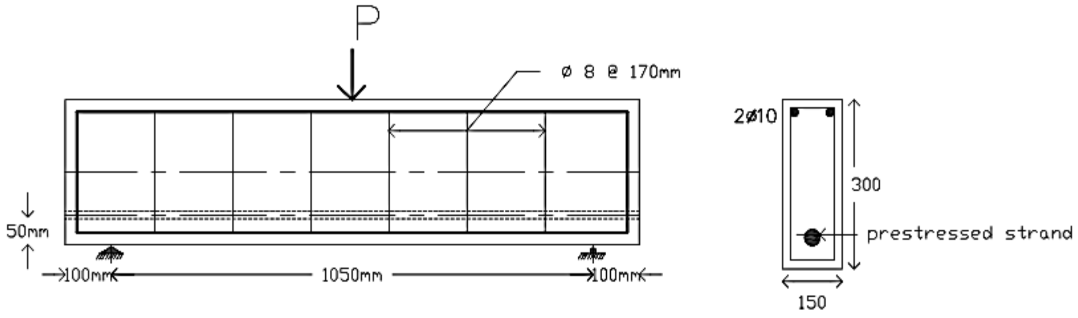

Figure 1. Reinforcement details of fully post-tensioned concrete beams without (CNT)

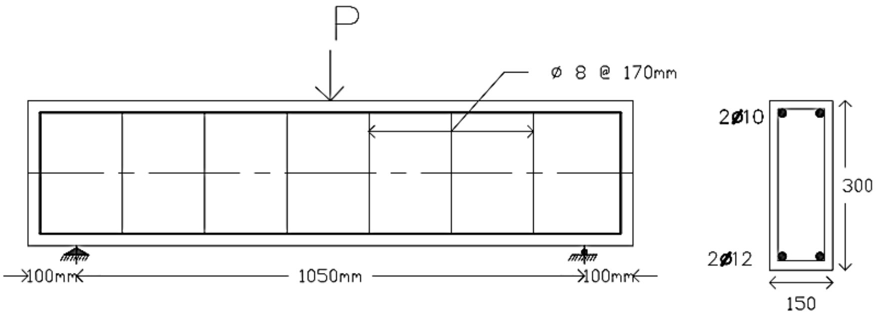

Figure 2. Reinforcement details of non-prestressed concrete beams without (CNT)

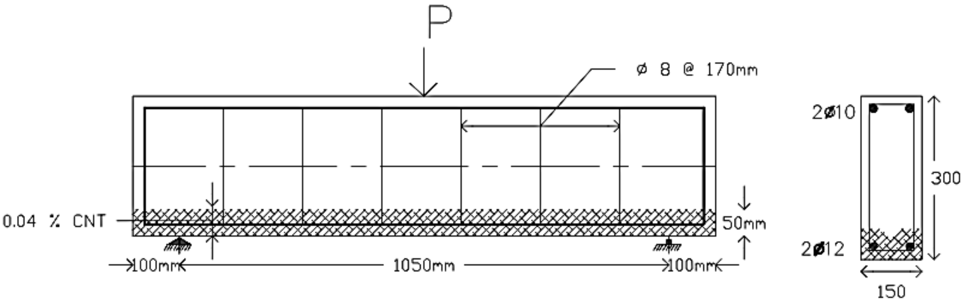

Figure 3. Reinforcement details of non-prestressed concrete beams with CNT

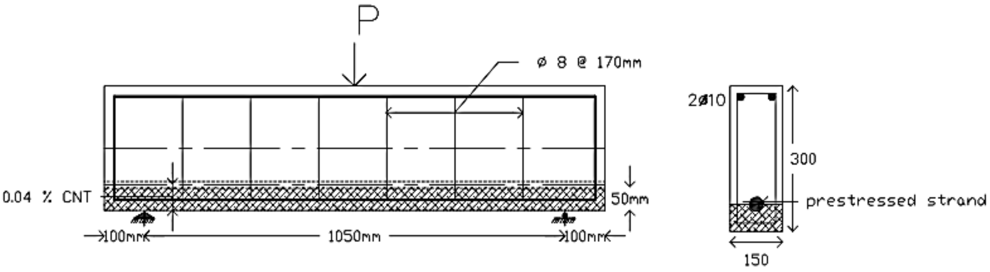

Figure 4. Reinforcement details of fully post-tensioned concrete beams with CNT

Figure 5. Anchorage zone of the tested prestressed concrete beam

3.2. Material Properties and Mix Preparations

Reinforcing steel: mild steel bars of 8mm diameter were used as stirrups, and the longitudinal reinforcement were deformed grade steel bars of 10mm, and 12mm diameters. Pre-stressing strand: Prestressed seven wires steel strand of total diameter 12.70 mm was used. The modulus of elasticity and tensile strength of the pre-stressed strand are 195 KN/mm², and 1724 N/mm², respectively, as reported by the manufacturer.

Anchorage Zone Details: Materials for anchorage plate were nodular cast iron, wedges: 20CrMnTi steel. Mono strand anchorage dimension had 127 x 57.1 mm.

For all tested prestressed beams, this consisted of the Portland cement - ASTM Type I. For concrete production; the aggregates are mixed by percentages of 35% and 65% for fines and coarse aggregate by volume respectively. Figure 6 shows the sieve analysis of the mixed aggregates analysis as compared to the Egyptian code of practice limitations.

A polycarboxylate admixture (Glenium C315 SCC) was used to improve the workability of concrete, and the dispersion of CNT in concrete mix, as shown in Table 2. Figure 7 shows the carbon Nano tubes particles size by TEM micrograph of local carbon Nano tubes particles.

Table 2. Concrete mixtures composition by weight (kg) per 1 m³

Cement	Agg. Coarse	Agg. fine	W	CNT	S.P	Fcu N/mm²
450	1168	629	180	0	3.3	40
450	1168	629	180	0.18	3.3	50

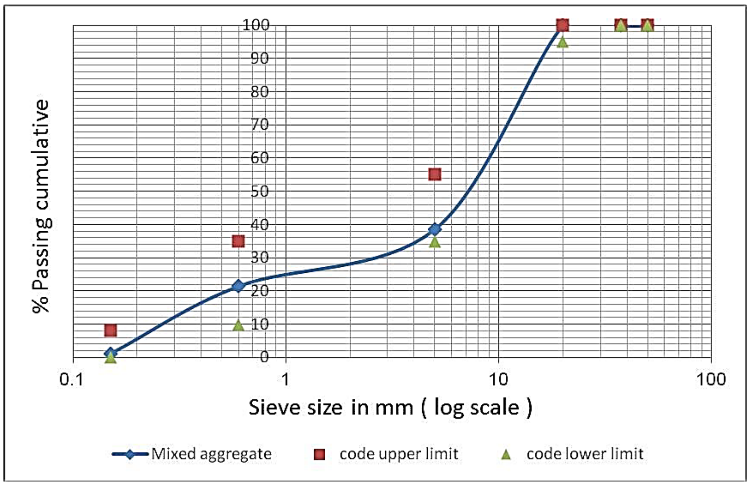

Figure 6. Mixed aggregates sieve analysis in comparison with the limits of the Egyptian code of practice

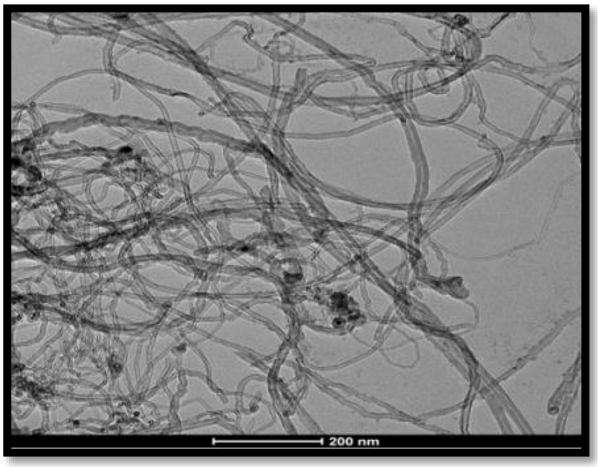

Figure 7. TEM micrograph of local carbon Nano tubes particles

3.3. Experimental Setup

The pre-stressing specimens were fabricated in two stages. The first stage was the fabrication of four reinforced concrete beams in steel form with concrete having a compressive strength of 40 for the whole section, except the CNT parts, the compressive strength with CNT reached 50 N/mm^2. The strand profile of fully post tension beam with and without CNT could be found in Figure 3 and 4. The second stage was the performance of pre-stressing force for four specimens using a pre-stressing jack as shown in Figure 8. After the concrete had been cured to the age of 28 days, the strands were stressed. The pre-stressing strand was positioned in the interior of a duct and fixed to the member stirrups using horizontal steel chairs. The steel plate was supported with the anchorage zone reinforcement to distribute the stress for the specimen cross section during pre-stressing. The stressing procedure was applied as per the instructions of the manufacturing company of the pre-stressing. The pre-stressing force jack 120 kN.

Figure 8. Jack pump and jack during tensioning

3.4. Testing Setup

The beams were subjected to point load at mid span using hydraulic jacks of 500-kN capacity. The loads were measured by a load cell of 300-kN capacity, the specimen was supported over two steel par using one free rod and restrained rod to simulate a roller support and a hinged support respectively. The beams were tested up to failure using a stroke control system. The data were collected using the system a data acquisition and "a lab view" software at a rate of 1 sample per second. The instrumentation in the beams comprised of displacement transducers (LVDTs) to measure deflections and load cells to measure support reactions, as shown in Figure 9. A sample of loading vs Time chart for the tests is shown in Figure 10.

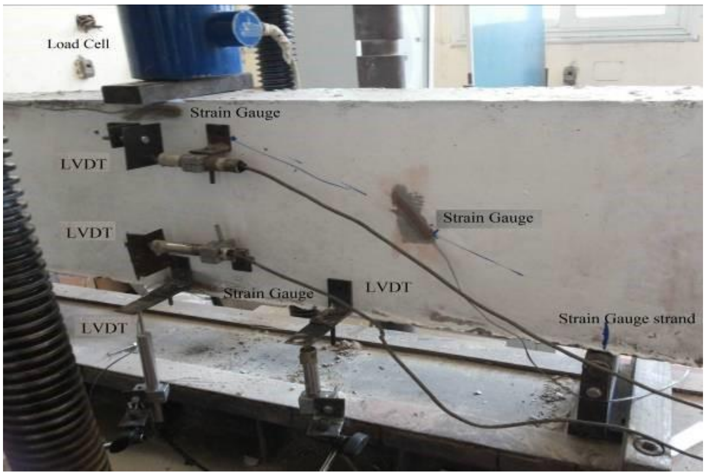

Figure 9. The instrumentation in the beam

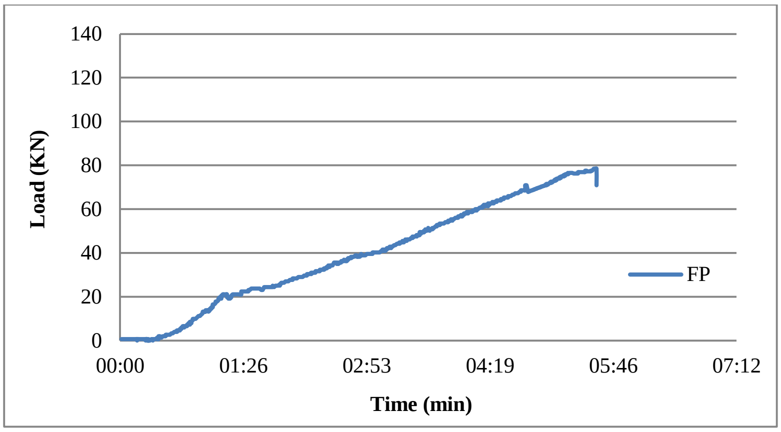

Figure 10. Fully prestressed Loading vs Time chart

4. Results and Discussion

The ultimate Load, crack Patterns, Modes of failure, and deflection, at critical sections were examined and the results will be presented hereunder.

4.1. Crack Patterns and Mode of Failure

4.1.1. Control Beam at Ambient Temperature

(a) Group (1); the crack pattern for non-prestressed beams with and without CNT:

Figure 11 showed that the crack pattern for non-prestressed beam without CNT was distributed along the beam and characterized by a large number of large cracks. While the crack pattern for non-prestressed beams with ratio (0.04%) of CNT at the mid-span of the beam characterized by a small number of small cracks. This is because of the presence of the CNT in the tension zone of the non-pre-stressed beams, that highly and significantly enhanced the crack propagation through decreasing the crack widths via either bridging of the Nano and micro scale cracks, or increasing the crack paths through the concrete matrix, and subsequently delaying the crack propagation and increasing the beam capacity, as can be seen in Figure 12.

The cracks started at the location of high flexural moment and then spread over the beam length as the load increased. The flexural cracks of non-prestressed beams with and without (CNT) started vertical then inclination with increase the loading. The failure of the non-prestressed concrete beams with and without CNT started by micro cracks and ended by concrete crushing. Its failure was ductile and occurred in the middle. The behaviours of these beams before the failure were ductile and gave a good warning before failure, because of the increase in deflection. The position of the failure of these beams was in the middle, or near to the middle, in the flexural zone.

(b) Group (2); the crack pattern for pre-stressed beams with (0, and 0.04 %) ratios of the CNT:

Figure13 showed that the flexural cracks of fully prestressed beams. The fully post-tensioned concrete beams without CNT had a cracking pattern at the location of the high flexural moment. The crack pattern of fully pre-stressed concrete beams without CNT was in the middle, or near to the middle, in the flexural zone. A large crack width and few numbers of micro cracks unlike the Non-prestressed beams have been observed. This could be due to the absence of non- prestressed steel as well as the effect of the pre-stressing force distributed over the length in constant pattern. Figure14 showed that the crack pattern of fully prestressed concrete beams with ratio 0.04 % of the CNT were in the middle, or near to the middle. A small crack width without any noticeable micro cracks compared to the other fully prestressed beams without CNT was noticed. This could be attributed to the previously mentioned effect of CNT in bridging the Nano and micro scale cracks, as well as increasing the crack paths through the concrete matrix, and subsequently delaying the crack propagation and increasing the beam capacity.

The mode of failure of the fully post-tensioned concrete beams with and without CNT was brittle and occurred in the middle. In all fully prestressed beams, the failure was destructive and accompanied by concrete splitting at the tension face. However, these beams behaviours before failure were brittle and gave less warning before failure compared to other beams. The positions of the failure of these beams were located in the middle, or near to the middle, in the flexural zone, as shown in Figures 13 and 14.

According to the previous observations, the carbon nano-tube improved the performance of beams. This is due to the reduction in the crack width and minimizing the crack distribution along the beam length.

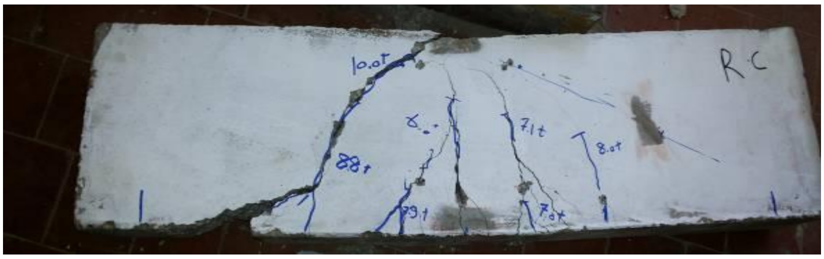

Figure 11. Crack pattern and mode of failure of a non-prestressed beam without CNT

Figure 12. Crack pattern and mode of failure of a non-prestressed beam with CNT (RC- CNT)

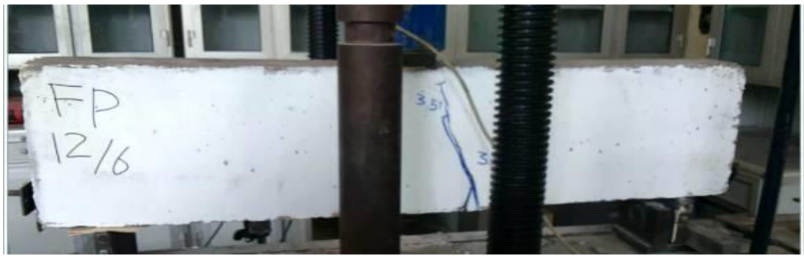

Figure 13. Crack pattern and mode of failure of the fully prestressed beam without CNT (FP)

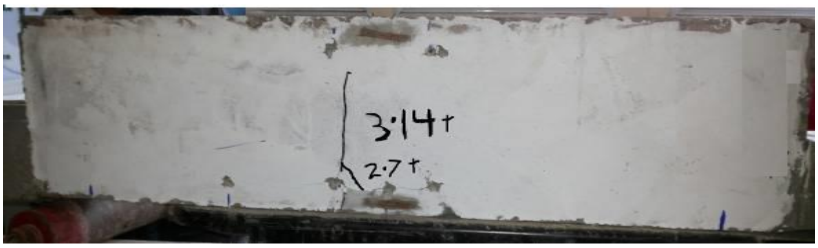

Figure 14. Crack pattern and mode of failure of the fully prestressed beam with CNT (FP–CNT)

4.1.2. Behavior of Beams under Elevated temperature

Crack pattern and modes of failure of the beams after elevated 400ºC were similar to that of the control beams. In addition to the following observations:

- The concrete color of the beams subjected to elevated temperature turned to pink.
- Non-uniform hair cracks in the elevated temperature areas were observed, because of the difference in expansion coefficient between concrete and steel.

As it can be observed from Figures 15 and 16, the flexural cracks of Non-prestressed beams with and without CNT under elevated temperature (Group 1); The crack pattern for Non-prestressed beams with CNT at the mid-span of the beam characterized by a small number of small cracks compared to the crack pattern for Non-prestressed beams without CNT under elevated 400ºC. Figures 17 and 18 show that the flexural cracks of fully prestressed concrete beams with and without CNT under elevated 400ºC. The crack pattern of fully prestressed beams with CNT was of smaller crack width located in the middle, or near to the middle of the beam compared to the crack width of the other fully post tension beams without CNT.

Figure 15. Crack Pattern and Mode of Failure of a Non-prestressed beam without CNT (RC- 400) under the Elevated temperature

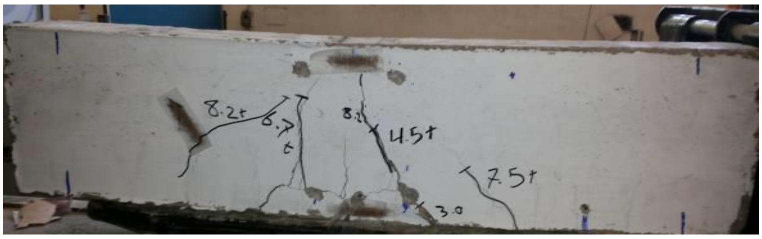

Figure 16. Crack Pattern and Mode of Failure of a Non-prestressed beam with CNT under Elevated temperature (RC –CNT-400)

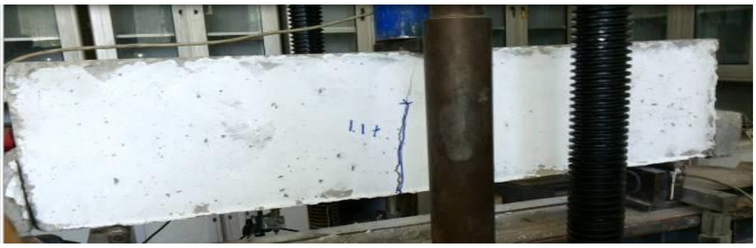

Figure 17. Crack Pattern and Mode of Failure of the fully prestressed beam without CNT after under temperature (FP – 400)

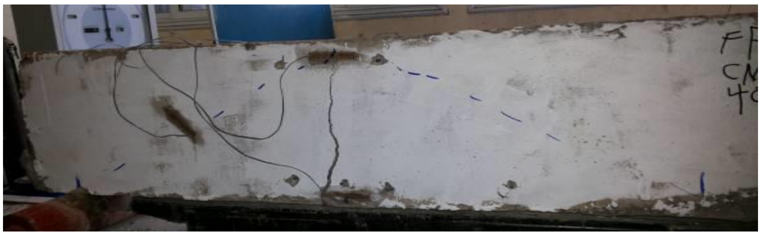

Figure 18. Crack Pattern and Mode of Failure of the fully prestressed beam with CNT under Elevated temperature (FP –CNT-400)

4.2. Load-Deflection Beam Behavior under Different Levels of Elevated Temperature

The effects of the load for mid-span deflections of all beams on the behavior of non-prestressed beams with and without CNT for the control and elevated temperature beams RC, RC-400, RC-CNT, and RC-CNT-400, As can be observed in Figures 19 and 20 respectively.

Generally, the subjection to elevated temperature decreases the load-carrying capacity of the beams. This can be attributed to the fact that heating causes a reduction in the beam stiffness, which is primarily due to the reduction in the modulus of elasticity of concrete and the reduction in the effective cross sectional area due to cracking.

It can be noticed that the load-deflection characteristics were largely similar up to the cracking load in the control and elevated temperature for beams with and without CNT. Beyond that, the beams with different ratios (0, and 0.04 %) of the CNT (RC, or RC-CNT) registered a smaller deflection at any given load than the other beams under elevated 400ºC, (RC-400, or RC-CNT-400) respectively.

The non-prestressed with CNT concrete beams (RC-CNT) registered a smaller deflection at any given load than the concrete beams without CNT (RC). While the non-prestressed without CNT concrete beams (RC-400) under elevated 400ºC had higher deflection at any given load compared to the non-prestressed with CNT concrete beams (RC-CNT-400) under elevated 400ºC. The non-prestressed with (0.04 %) of the CNT concrete beams (RC-CNT) registered a smaller deflection at any given load than the other beams. While the non-prestressed without CNT concrete beams (RC-400) under elevated 400ºC had higher deflection at any given load compared to the non-prestressed concrete all of the other beams. The general load versus mid-span deflection behaviours of RC beams and of that under elevated temperature at 400°C were approximately similar. On the other hand, for post-fire RC beams with CNT under elevated temperature at 400°C, the load versus mid-span deflection relations indicated softer behaviours in general as compared with those of the control RC beams. This can be attributed to the weaker bond strength between the concrete and steel reinforcement or decomposition of the concrete components itself.

The effects of the load for mid-span deflections of all beams on the behavior of fully post tension beams with and without CNT for the control and elevated temperature beams, Figures 21 to 22 shows the load-deflection curve of fully prestressed with different ratios (0, and 0.04 %) of the CNT concrete beams for the control and elevated temperature beams FP, FP-400, FP-CNT, and FP-CNT-400. It can be observed that the load-deflection characteristics were similar up to the cracking load for the control and elevated temperature beams. Beyond that, the fully prestressed without CNT concrete beams (FP) registered a smaller deflection at any given load than the other beams under elevated 400ºC, (FP-400).

It can be observed that the load-deflection characteristics were different from the beginning of the loading and up to the cracking load for the control and elevated temperature beams. The fully pre-stressed with CNT concrete beams (FP-CNT) registered a smaller deflection at any given load than the other beams under elevated 400ºC, (FP-CNT-400).

The fully prestressed with CNT concrete beams (FP-CNT) registered a smaller deflection at any given load than the fully prestressed beams without CNT (FP). While the fully prestressed without CNT concrete beams (FP-400) under elevated 400ºC had higher deflection at any given load compared to the fully prestressed with (0.04%) of the CNT concrete beams (FP-CNT-400) under elevated 400ºC. The fully prestressed with CNT concrete beam FP-CNT registered a smaller deflection at any particular load than the other beams, while FP -400 had higher deflection at any load compared to the fully pre-stressed concrete all of the other beams.

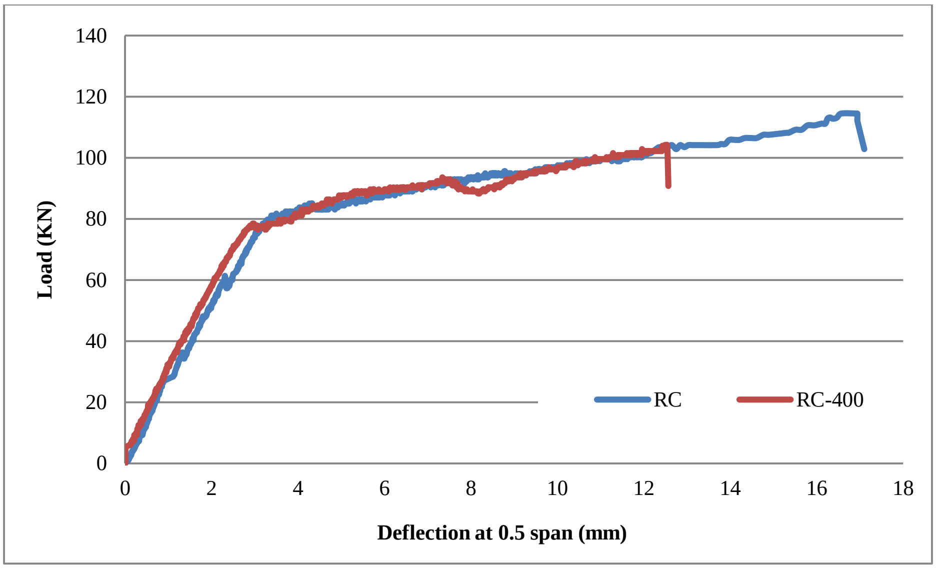

Figure 19. Load- Mid Span Deflection Relationship for Non- prestressed beam under elevated temperature without CNT (RC, and RC-400)

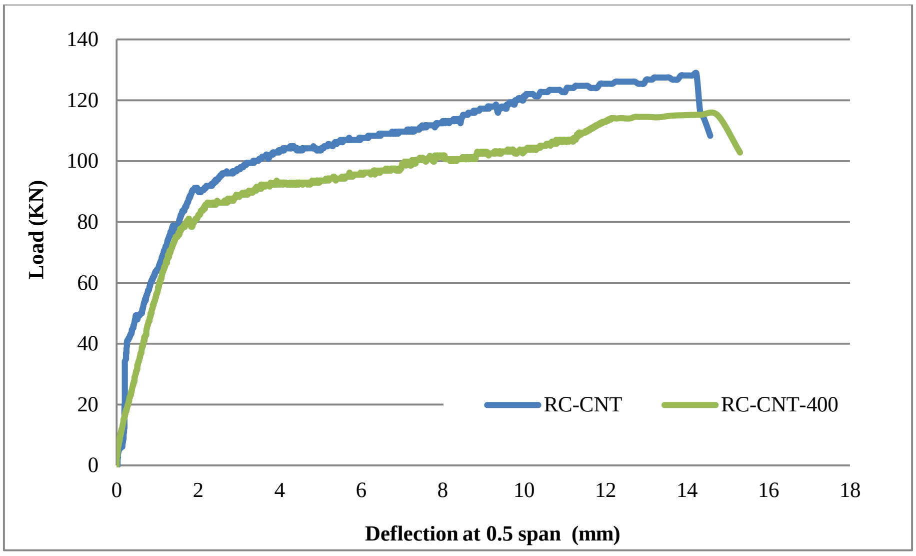

Figure 20. Load- Mid Span Deflection Relationship for Non- prestressed with CNT beam under elevated temperature (RC-CNT, and RC-CNT - 400)

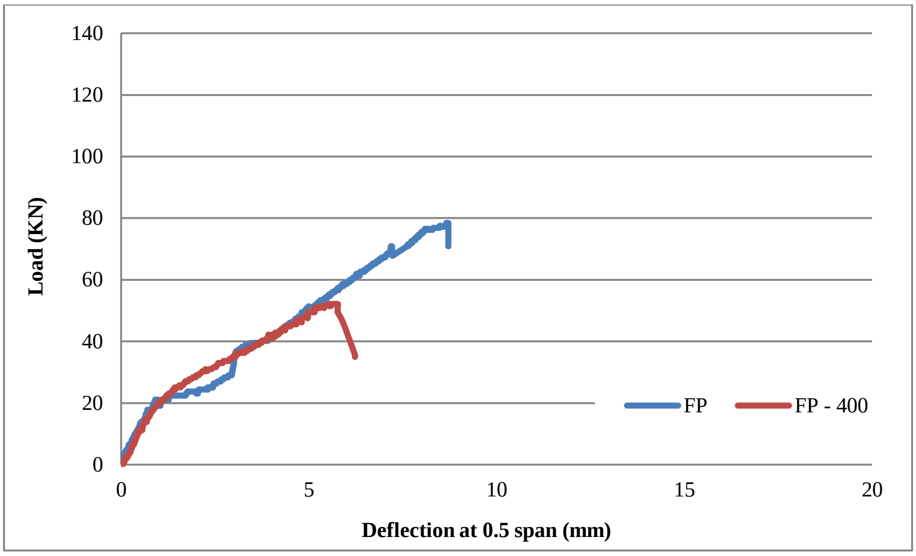

Figure 21. Load - Mid Span Deflection Relationship for fully prestressed concrete beams without CNT under elevated temperature FP, and FP-400

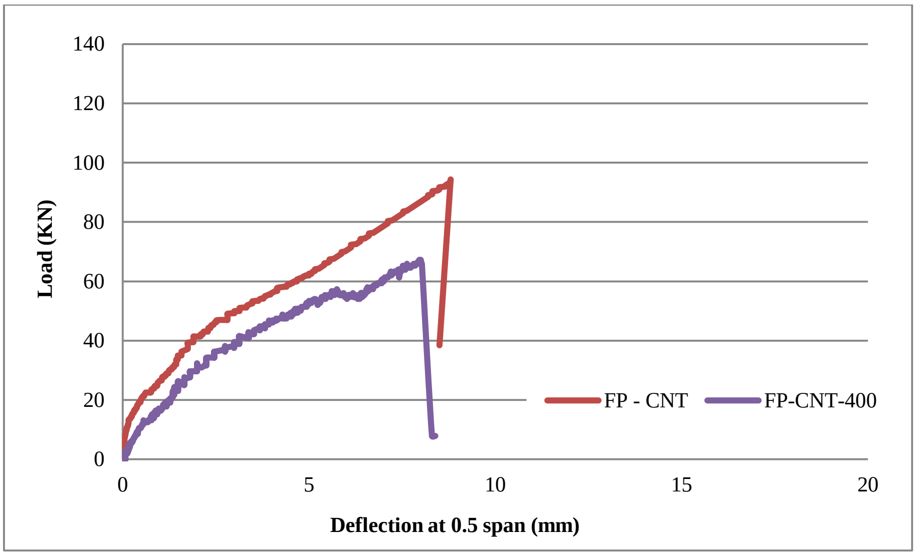

Figure 22. Load - Mid Span Deflection Relationship for fully prestressed with CNT concrete beams under elevated temperature FP-CNT, and FP-CNT-400

4.3. Deflection Distribution along the Span of Beams at Different Load Levels

Figures 23 and 24; show the deflection profiles of the beams at different loading phases. It can be noticed that, the deflection throughout the beam span measured at 0.25, 0.5, and 0.75 of the span for non-pre-stressed beams without CNT under ambient temperature showed flatter mode of deformation at small load values as compared to the same beam after subjection to 400ºC elevated temperature due to the effect of heating on the deterioration of the beam elastic stiffness, in addition, the non-pre-stressed beam without CNT failed at higher load value and got deformed for higher deflection value than the beam under elevated 400ºC at the failure load.

Figures 25 and 26; show the deflection profiles of the beams at different loading phases. It can be observed that, the deflection throughout the beam span measured at 0.25, 0.5, and 0.75 of the span for the full pre-stressed beams without CNT under ambient temperature showed flatter mode of deformation at very small load value (from the beginning of loading till 20 kN) as compared to the same beam after subjection to 400ºC elevated temperature, in addition, and beyond that loading level till the failure load, the full pre-stressed beam without CNT showed higher deformations and failed at higher load value than the beam under elevated 400ºC at the failure load.

The decrease in the flexural performance of full pre-stressed beams under elevated temperature is attributed to test steps as the beams were subjected to elevated temperature 400ºc for 2 hours and then left to cool to room temperature before being finally up to failure.

By comparing the observations from Figure 23 with that of Figure 27, the deflection throughout the beam span measured at 0.25, 0.5, and 0.75 of the span for non-pre-stressed beams with and without CNT. The presence of the CNT showed flatter mode of deformation as compared to the beam without CNT at small load values (up to 65 kN), indicating the increase in the beam stiffness which could directly affect the serviceability limit state of the beams with CNT. Moreover, the CNT beam failed at higher load value and lower deflection value than the control beam which indicates the effectiveness of the CNT in increasing the modulus of elasticity of the beams as well as increasing its tensile strength capacity. The increase in the tensile capacity could be due to the well-reported effect of the CNT in arresting the cracks, and bridging of the cracks at their Nano-scale to the micro scale level of propagation.

As can be observed from Figure 25 and as compared to Figure 29, it can be seen that, the deflection pattern over the beam span measured at 0.25, 0.5, and 0.75 of the span for the fully pre-stressed beams with and without CNT. The presence of the CNT showed flatter mode of deformation as compared to the beam without CNT at all load values, in addition, and although, the CNT beam failed at higher load value than the control beam, it experienced almost the same deflection value, this significantly indicates the effectiveness if the CNT in increasing the modulus of elasticity of the beams as well as increasing its tensile strength capacity. The increase in the tensile capacity could be due to the well-reported effect of the CNT in arresting the cracks, and bridging of the cracks at their Nan scale to the micro-scale level of propagation. The noticed deflection mode indicates the significance of the CNT addition in enhancing the beam stiffness.

From Figures 27 and 28, it can be noticed that, the deflection throughout the beam span measured at 0.25, 0.5, and 0.75 of the span for non-pre-stressed beams with ratios (0.04%) of the CNT before and after the subjection to elevated temperature. With the presence of (0.04%) CNT, a smoother mode of deformation was observed for the beam tested in room temperature as compared to the beam tested after the subjection to 400ºC elevated temperature for 2 hours, this occurred at load levels up to 65 kN, in addition, the non-pre-stressed beam with CNT failed at higher load value and lower deflection value than the same beam after elevated temperature (400ºC) exposure, the performance that illustrates the reported decrease in the flexural performance of non-pre-stressed beams under elevated temperatures. From Figure 29 with Figure 30, the same performance was observed when comparing the full pre-stressed beams containing (0.04%) CNT: before, and after the subjection to elevated temperature.

Finally, the gain in strength found in beams with CNT after subjected to elevated temperature and as compared to those without CNT, could be for the reported possible reason that the further hydration process was impeded by the addition of the CNT and the strength was improved greatly at 400ºC due to that the CNT works as channels for the release of high-pressure steam to reduce the crack growth due to the steam.

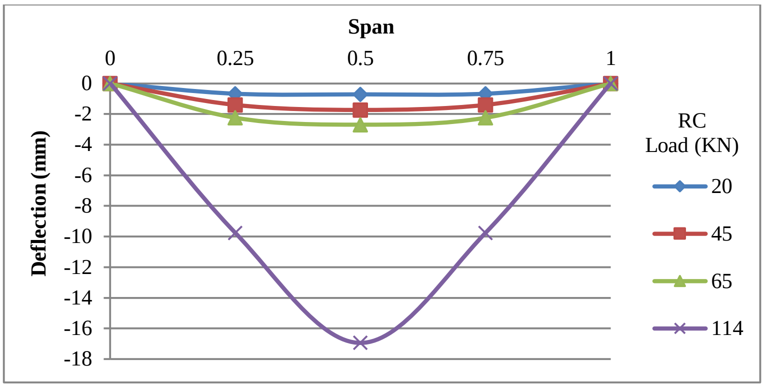

Figure 23. Deflection distribution along span at different load levels for none pre-stressed concrete beam without CNT (RC)

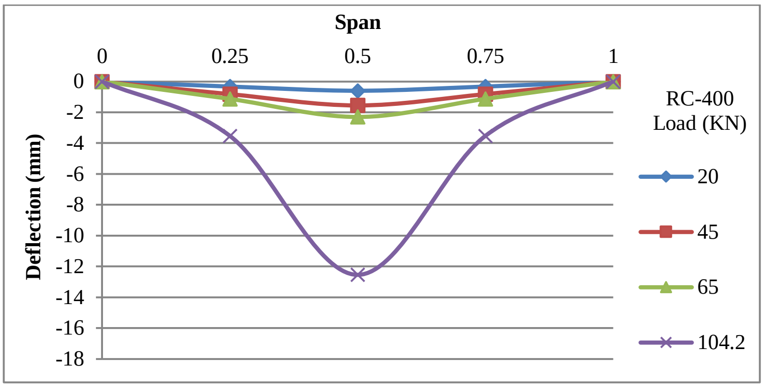

Figure 24. Deflection distribution along span at different load levels for Non-pre-stressed concrete beam without CNT under elevated temperature (RC-400)

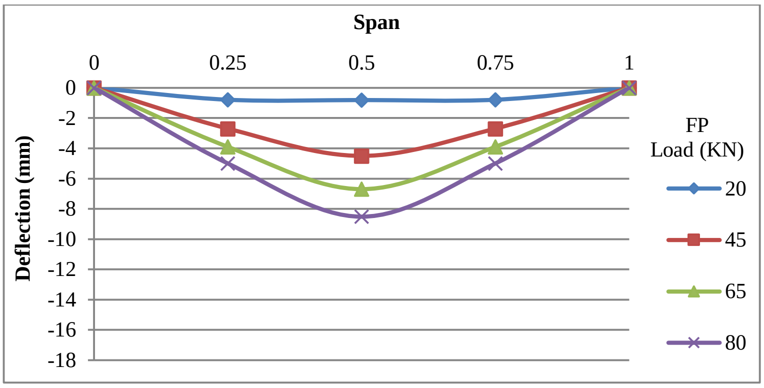

Figure 25. Deflection distribution along span at different load levels for fully pre-stressed concrete beam without CNT (FP)

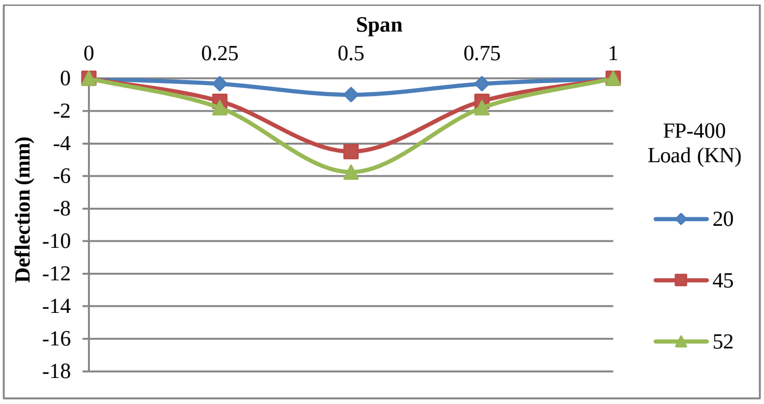

Figure 26. Deflection distribution along span at different load levels for fully pre-stressed concrete beam under elevated temperature without CNT (FP-400)

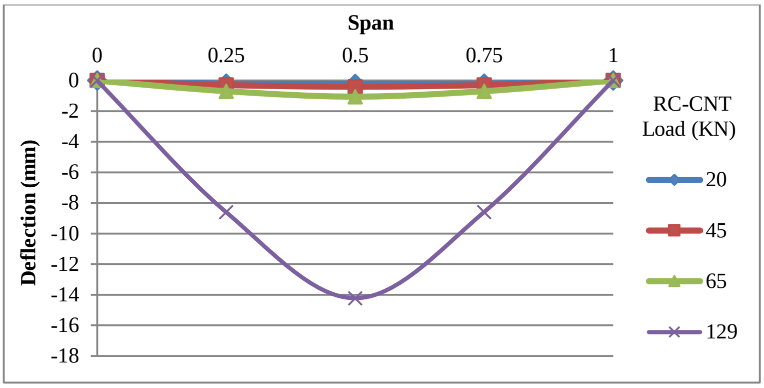

Figure 27. Deflection distribution along span at different load levels for Non-pre-stressed with CNT concrete beam (RC-CNT)

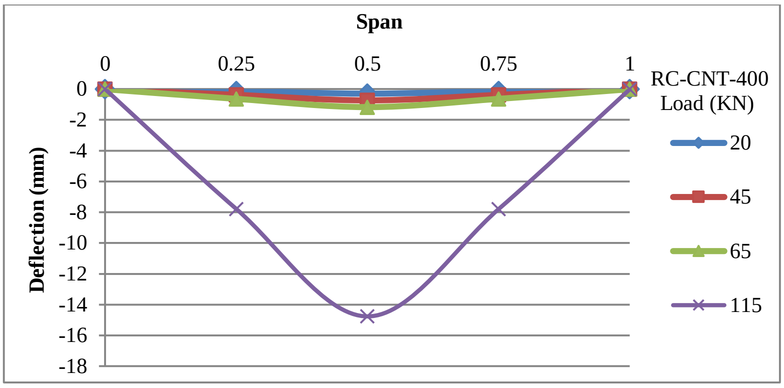

Figure 28. Deflection distribution along span at different load levels for Non-pre-stressed with CNT concrete beam under elevated temperature (RC-CNT-400)

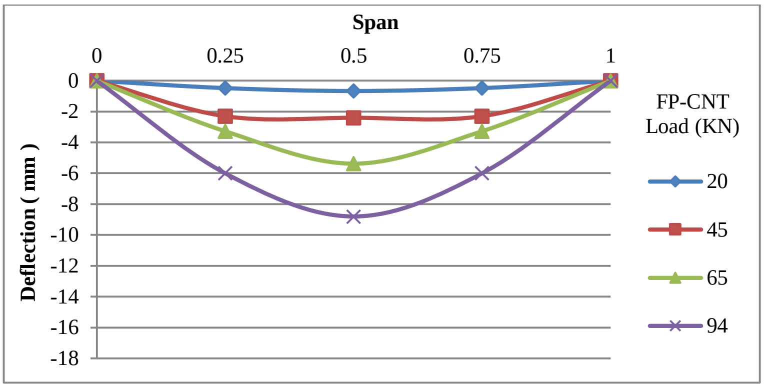

Figure 29. Deflection distribution along span at different load levels for fully pre-stressed with CNT concrete beam (FP-CNT)

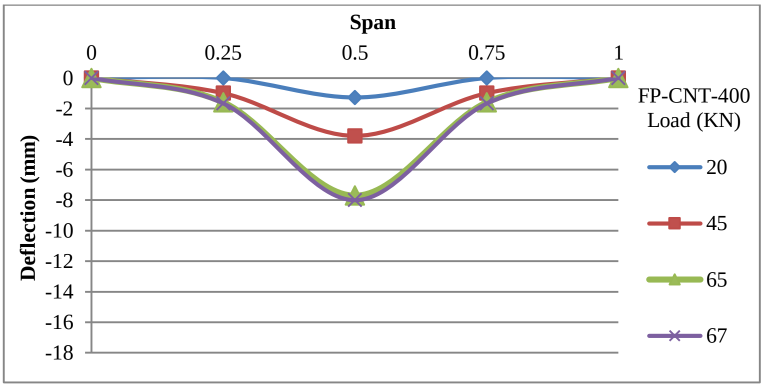

Figure 30. Deflection distribution along span at different load levels for fully pre-stressed with CNT concrete beam under elevated temperature (FP-CNT-400)

5. Conclusions

The following conclusions can be drawn:

- The ultimate load of the non-pre-stressed beam with the presence of the CNT at the lower 50mm in the tension zone showed a gain of 13% as compared to the same beam without CNT.
- The ultimate load of the fully pre-stressed beam with the presence of the CNT at the lower 50mm in the tension zone showed a gain of 21% as compared to the same beam without CNT.
- For the non-pre-stressed beams, the load capacity of the beam with CNT after exposure had a similar load capacity as the beam without CNT before exposure to high temperature.
- As for fully pre-stressed beams, the presence of the CNT in the tension zone of the beams had shown a significant effect on the resistance of elevated temperature, as the residual load capacity of the beams after exposure to high temperature was almost 1.5 times the beams without CNT.
- The reinforcing effect of the CNT is most obvious at 400 ºC, which is due to the potential of the CNT as channels for releasing high-pressure steam.
- The non-prestressed with CNT concrete beams (RC-CNT) registered a smaller deflection at any given load than the other beams. While the non-prestressed without CNT concrete beams (RC-400) under elevated 400ºC had higher deflection at any given load compared to the non-pre-stressed concrete all of the other beams.
- The fully prestressed with (0.04%) of the CNT concrete beam FP-CNT registered a smaller deflection at any particular load than the other beams, while FP-400 had higher deflection at any load compared to the fully pre-stressed concrete all of the other beams.

It can be concluded for specimens that the presence of carbon nanotube (CNT) had improved the flexural performance of none and fully pre-stressed beams under elevated temperature.

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7. Conflict of Interest

The authors declare no conflict of interest.

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