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RESEARCH ARTICLE

FIRE EFFECT ON LIGHT WEIGHT CONCRETE BEAMS IN FLEXURAL

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Abstract

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This research was commenced with the objective of investigating the lightweight concrete "LWC" behavior when exposed to fire by partial aggregate replacement with polystyrene foam under concentric loads, experimentally. This is attributed to the fact that the reduced mass concrete reduces the imposed lateral load during earthquakes, Literature review was carried out in the field of LWC in order to determine the research gaps or weak points to commence this research.From the analysis of tested results showed that the crack width increased and the numbers of cracks increased due to exposing the tested beam to fire .The ultimate load decreased by subjected to fire by average 26.263% while the deflection increased with average 15.42% for beam and the ductility slightly decreased by average 13.1% because of the decreasing in the deflection corresponding to the maximum load where the energy absorption capacity decreased with average 29.7% for beam.

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Introduction:-

The majority of current research on concrete is focused on high performance concrete, which is an economical material that achieves high performance requirements, including durability. For the construction industry to be efficient and profitable, lightweight concrete (LWC) is important. The main benefit of LWC is the decrease in structural dead load, base loads, sections of all structural elements and finally the overall cost of the construction. Additionally, the reduced mass will simplify and reduce the lateral load carrying system by reducing the lateral load that will be placed on the structure during earthquakes. Reduced weight results in a proportionately decreased hydrostatic pressure on formwork for LWC. Additionally, it is suggested that additional water is present for internal curing in lightweight aggregates due to water absorption into their porous structure. In order to evaluate the structural behavior and design in the second phase, including the study carried out in this thesis, a variety of structural RC elements (beams, slabs, etc.) are manufactured using the LWC produced in the first phase.

Since the eighteenth century, lightweight concrete (LWC) has been utilised in construction. In order to lower the price of Reinforced Concrete (RC) structures, it is crucial. The primary factors utilised to decrease concrete's density are the weight, type, and ratio of coarse and fine aggregate, [1 - 4].

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There has been investigation into two foam concrete mixtures manufactured with and without sand, and attempts have been made to choose the foam concrete mixture's proportions for the ideal plastic density of 1900 kg/m3. They reached the conclusion that because the foam concrete's 28-day compressive strength is less than 17.0 MPa, the mixed percentage employed in this study was not suitable for structural purposes, [5].

Presented a study that used two different types of additives—silica fume and fly ash—along with a water reducer agent to improve pre-formed foam concrete with densities ranging from 1300 to 1900 kg/m^3.. The outcomes demonstrated that the additions enhanced foam concrete's pore structure, increased strength, decreased water absorption, and slightly increased thermal conductivity, [6].Investigated the effects of polyolefin fibre on the compressive and flexural properties of foam concrete with densities ranging from 1300 to 1600 kg/m3 at relatively low volume fractions (0.0%, 0.20%, 0.40%, and 0.60%). According to the test results, adding polyolefin fibers only marginally increased the foam concrete's compressive strength and flexural strength by 4.3% and 9.3%, respectively, [7].

Generally, concrete holds up well in building fires. Concrete, however, can suffer serious damage if exposed to fire for a prolonged amount of time at particularly high temperatures. A slight strength drop can be allowed because the pre-fire compressive strength of concrete frequently surpasses design requirements. However, extreme temperatures have the potential to significantly reduce concrete's compressive strength to the point where it loses all effective structural strength, [8].

Experimental Programs

Tested Specimens And Parameters

The performed experimental work contains two beams with typical dimension 300 mm depth, 1700 mm total length, 150 mm total width, 50 mm cover and 1500 mm span. The typical concrete specimen's dimensions and reinforcement details are shown in **Fig. 1**.

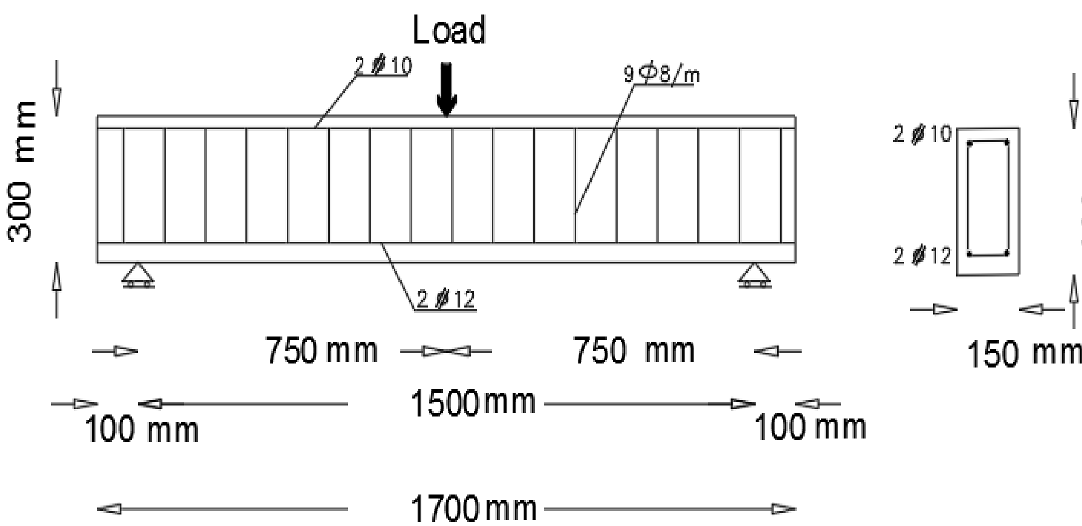

Fig. 1:- Dimension and the Reinforcement Details.

The parameter considered in this work is the effect of fire on lightweight concrete beams. The first beam B1 (NNC) was loaded by concentric vertical load. The second beam was exposed to fire to reach 500° c during half an hour. Then loading the beam with ultimate load after cooling by air B4 (FNC) as shown in **table 1.**

Table (1):- The Experimental Program.

Specimens	Heating Temp. ° c	Vertical stirrups	Main Steel	Compression strength
B1(NNC)	Non	9D8@1000mm	2D12mm	2D10mm
B4(FNC)	500	9D8@1000mm	2D12mm	2D10mm

Material Properties:
Each of the test subject was created using materials found around. A type of plastic made from styrene is polystyrene foam. The concrete mix contained cellular foam, which is a lightweight, stiff material. As seen in **Fig.2**, silica fume was added to polystyrene foam, which has good moisture resistance and is immune to rot, mildew, and rust. Superplasticizer was employed to produce lightweight concrete that was workable.

Fig. 2:- Polystyrene Foam.

High strength concrete has been produced using silica fume. It is a product created when high quality quartz is reduced with coal in electrical core furnaces to produce silicon. The fume is gathered from the fumes exiting from the furnaces and contains a lot of amorphous silicon dioxide and extremely small, spherical particles. When measured using nitrogen adsorption techniques, silica fume is made up of very small vitreous particles with a surface area of about 20000 m2/kg. Silica fume reacts with the lime during the hydration of cement to produce stable cementation compounds due to its extreme fineness and high silica content. The usage of silica fume as a component of the water-reducing admixture with high range has become possible.

Super Plasticizer It works effectively to reduce the amount of water in the concrete mix. In order to fully hydrate the cement particles, it is mostly required to develop concrete. As per ASTM C494, 2001 of type V, the used super-commercial plasticizer's name is VISCOCONCRETE-3425.

As indicated in **table2**, the mixture included natural sand as the fine aggregate, fine crushed stone with a nominal maximum size of 10 mm as the coarse aggregate, fresh ordinary Portland cement, polypropylene fibre, and tab water. Polystyrene foam, silica fume, and super plasticizer were also added.

Table (2):- Mix proportions/m3 for the LWC.

Concrete Type	Cement (kg)	Sand (kg)	Coarse Aggregate (kg)	Polystyrene Foam (liter)	Water (liter)	Silica fume (kg)	Super-plastizer (liter)	Polyprop-ylene Fiber (kg)	Density (kN/m^3)
LWC	500	630	630	400	135	20	40	0.90	18.1

The compressive strength lightweight foam concrete is approximately 30 MPa, and the yield strength of the used steel bars, according to the manufacturer, was equal to 360 MPa.

1.1. Preparation Of Specimens:
Wood forms were used to cast beams at one time. These wood forms shown in **Fig. 3** and the reinforced bars shown in **Fig. 4**. The strains of main RFT were then placed in their position in the forms. Before casting the concrete, the forms were wetted by water. Casting the concrete took place immediately after mixing. A mechanical vibrator was

used to compact the concrete to ensure full compaction. After one day the beams was removed from forms. The specimens were covered sheets and sprinkled with water for a week, then left in the atmosphere of laboratory until tested.

Fig. 3:- Wood Forms of Rectangular Beams.

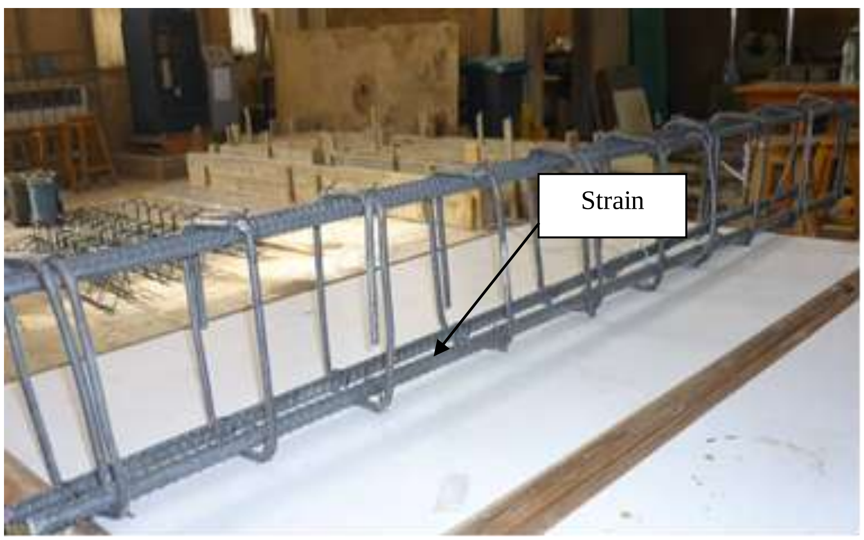

Fig. 4:- Steel Mesh of Rectangular Beams.

Test Setup And Instrumentation:

All tested beams specimens were supported on a special setup during firing and loading, as shown in **Fig. 5** and **Fig. 6**. The setup for firing beams consisted of a steel frame formed of I-beams resting on four steel columns to support the beams during firing. The span of the tested beams between supports is 1500 mm. The setup for loading beams consisted of a steel frame formed of I-beams acting as a lever. Two end of the beam was attached to the strong floor of the laboratory using threaded steel rods, which provided a hinge support for the lever. The lever beam applied its reaction load in the center of the tested beam at a distance equal to 0.75m from the hinged end of the lever.

Fig. 5:- Test Setup for Specimens during Loading.

Fig. 6:- Test Setup for Specimens during Fire.

Special furnace was constructed and prepared for this study with dimension 1500mm width, 1500mm length and 1400mm height. The fire flame system that was used consisted of a two line of gas pipes with 7-flame nozzles for each line as.

The vertical deflection of the tested beams was recorded using dial gauge with accuracy 0.01 mm. Three dial gauges was used to measure the vertical deflection for the vertical loads specimens. The positions of dial gauges at loading were 37.5mm from the lever and in the mid span of the beams tested specimens were showed in **Fig. 7**.

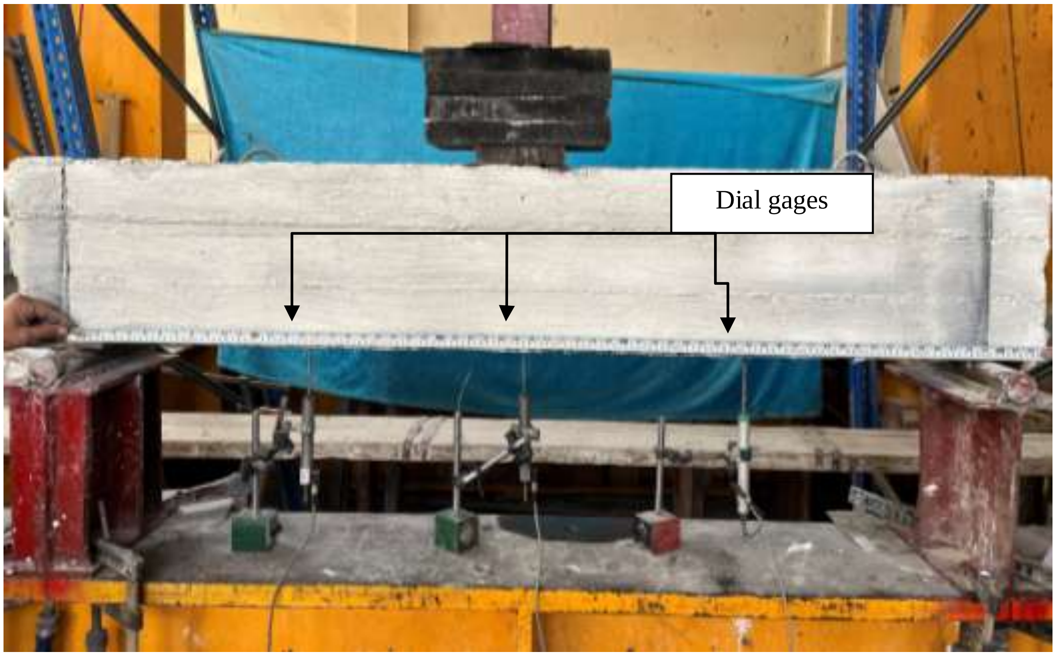

Fig. 7:- Positions of Dial Gauge for Load Specimens.

Test Results And Analysis:-
Ultimate Load And The Type Of Failure:

Table 3 summarizes the outcomes of the experiments for all specimens as the ultimate loads and the type of failure. The ultimate load decreased when expose beam to fire as shown in **Fig. 8**.

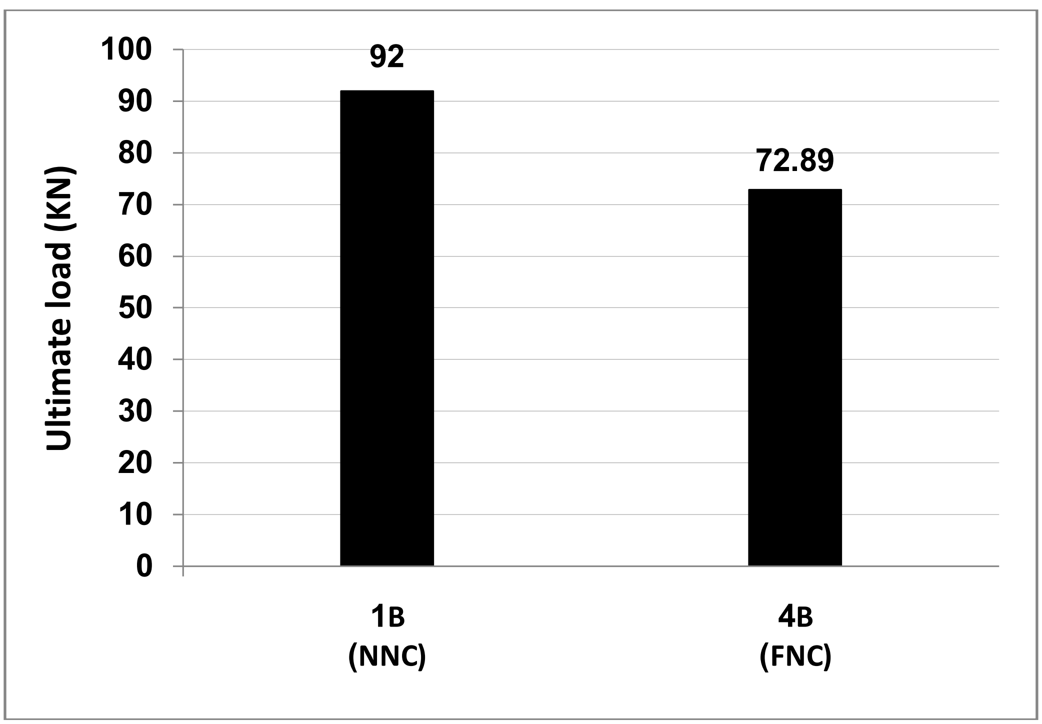

Fig. 8:- The Ultimate Load for Tested Specimens.

Table 3:- Ultimate Load, Deflection, Energy absorption, Stiffness, Ductility and Failure Type for All Tested Specimens.

Specimen Code	Cracking load (KN)	Ultimate load (KN)	Vertical deflection (mm)	Energy absorption (KN.mm)	Initial stiffness (KN/mm)	Yield stiffness (KN/mm)	Ductility	Failure Type	Cracks Number
B1 (NNC)	52.531	92	38.76	3282.8	87.71	68.56	11.03	Flex-ural	14
B4 (FNC)	56.871	72.89	33.58	2305.9	87.61	63.54	9.58	Flex-ural	18

Crack Patterns And Modes Of Failure:
The cracks patterns and modes of failures for the tested specimens of each beam taking the effect of fire are analyzed as follows. as shown in **Fig. 8**.

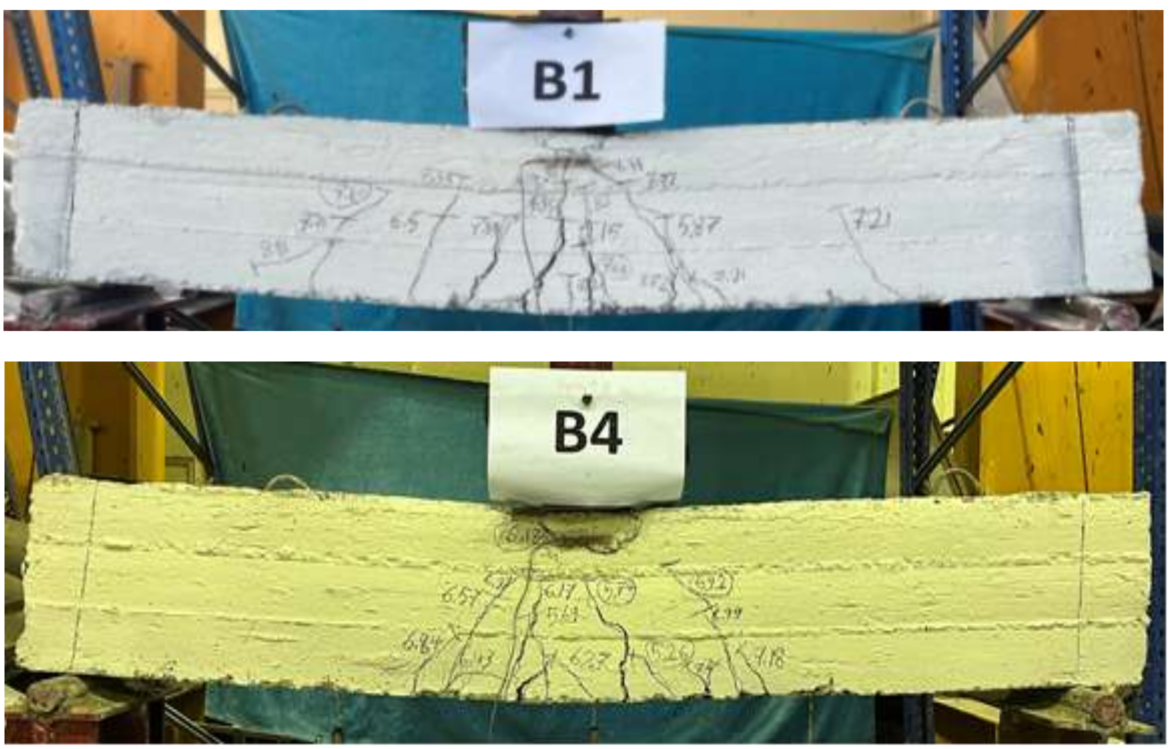

Fig. 9:- The Crack Patterns for B1(NNC) and B4(FNC).

When exposed beams to fire that caused change in the mode of failure and crack distribution. the tested specimens (B1(NNC) and B4(FNC)) are shown in Figure (9). The number of cracks increased and the crack width increased due to exposing the tested specimens to fire.

Load Deflection Curve:
It is clear from **Fig. 10** that the failure loads of tested specimens control beams B1 (NNC) not exposed to fire and B4 (FNC) exposed to fir were 92kN and 72.89kN respectively. The failure loads for tested specimens B1 (NNC) and B4 (FNC) decreased about 26.263% when subjecting to fire compared to control specimen B1 (NNC). Moreover, at failure load, the deflection of tested specimens B1 (NNC) and B4 (FNC) were 38.76mm and 33.58mm respectively. The percentage increase in deflection for B4 (FNC) was 15.42% for specimens subjected to fire-compared specimen B1 (NNC). The stiffness of the unfired specimen is stiff than the fired one. In **Fig. 11** that show the change in concrete strain in the beams. The stiffness decrease in beam B4 (FNC) that exposed to fire. The ductility increased by exposed beam to fire by 29.7%.

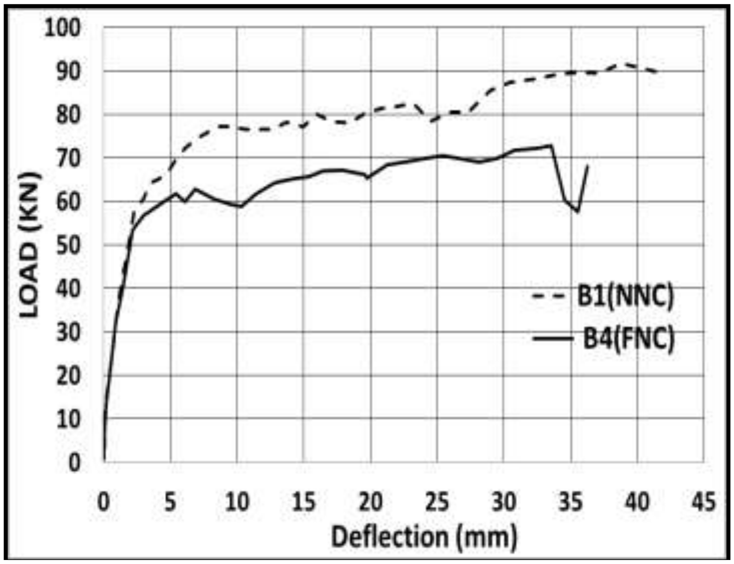

Fig. 10:- Effect of Fire on Load Deflection Curve.

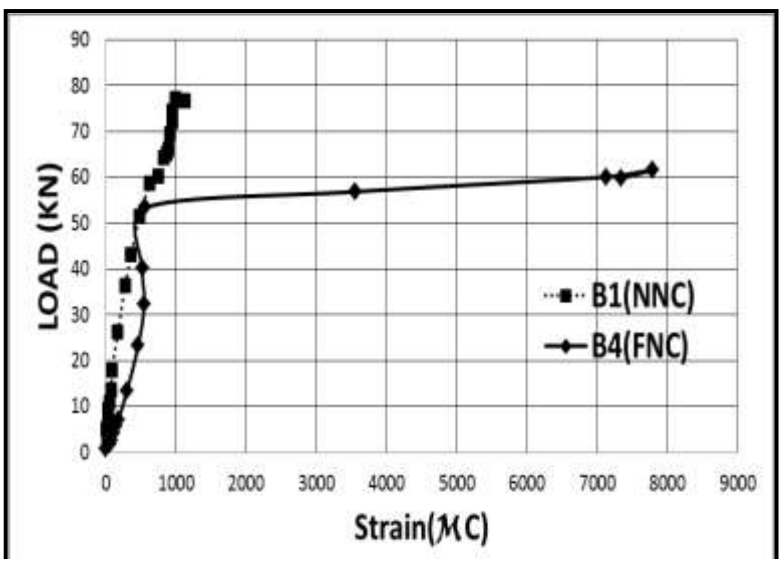

Fig. 11:- Effect of strengthen on Load Concrete strain Curve.

Theoretical Study:
In this section, the experimental and theoretical results using ACI-318 and ECP203 are compared to evaluate the proposal modification factors in polystyrene foam concrete. Finally, the proposed equation considering the effect of fire in LWC.

Evaluation The Experimental Results According To Different Codes

By comparing the experimental results and analytical maximum forces due to ACI-318 [9] and ECP203 [10] and codes, **equations (1)**, **(2)** and **(3)** are as follows.

$M_{ECP203} = A_S F_y (d - \frac{a}{2})$ … (1)

$M_{ACI318} = \lambda A_S F_S (d - \frac{\beta 1 C}{2})$ … (2)

β 1: the ratio of depth of equivalent rectangular stress block to depth of the neutral axis.

C: the distance from extreme compression fiber to the neutral axis atultimate capacity of the strengthened beam. λ : ACI318 LWC modification factor equal 0.75.

For beams were exposed to fire, the reduction factors for compressive strength of concrete and yield strength of reinforcement steel at elevated temperatures according to ACI318 as shown in **table 4**.

Table 4:- The Reduction in Compressive Strength of Concrete and Yield Strength of Reinforcement Steel at 500 C° According to ACI318.

Reduction factor	**LWC**
	ACI318
Compressive strength of concrete	0.95
yield strength of reinforcement steel	0.6

Table 5 shows comparisons between the experimental beams and the predicted ones according to the different code. The values [PTest / P from code] represent the failure load of each beam divided by the predicted load.

Table (5):- Test Results Compared with Different Codes.

Specimens	**Specimens code**	**Heating Temp (°C).**	**UltimateLoad (P_{Test}) (kN)**	**P_{ECP203} (kN)**	**P_{ACI318} (kN)**	**P_{Test}/ P_{ECP203}**	**P_{Test}/ P_{ACI318}**
B1	(NNC)	NON	92	56	44.3	1.64	2.07
B4	(FNC)	500^0	72.89	56	26.5	1.30	2.75

From **Table 5** the comparison of the experimental and analytical values of the tested beam by ACI-318 and ECP203 values. The ratio between the experimental analytical results in the foam concrete shows that the ratios increased when exposed to fire in ACI-318. From this, we concluded that correlation Factors greater than unity are required for the modification factor of foam concrete. Moreover, the reduction factor of compressive strength during fire must be less than unity for the tested specimens.

Generally, as shown in **Fig. 12** , The Egyptian code ECP 203-2017 is different to the American code ACI 318-08 in LWC beams and the beams that exposed to fire.

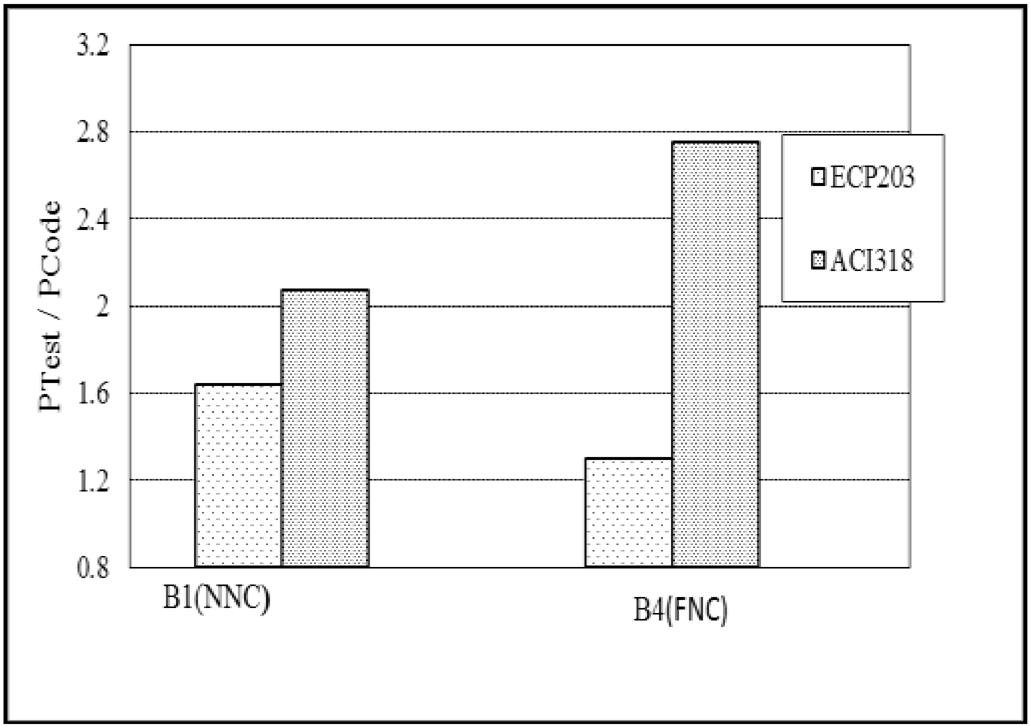

Fig.12:- Comparison between Test Result and Different Codes.

Conclusion:-

By studying the behavior of structural lightweight foam concrete beams when exposed to fire, we found that:

1. For lightweight polystyrene foam concrete beams exposed and not exposed to fire, the failure mode for the tested specimens beams was flexural failure, the crack width increased and the numbers of cracks increased due to exposing the tested specimens to fire.
2. By comparing the behavior of the structural lightweight polystyrene foam concrete beams exposed to fire and not exposed to fire, we find that:
3. The ultimate load decreased by 26.263% % in polystyrene foam concrete exposed to fire and increase in deflection for polystyrene foam concrete exposed to fire by15.42% .
4. The modification factor in compressive strength according to ACI-318 and ECP-203 should be modifie.
5. The application of structural foam concrete in the building industry needs more theoretical and experimental research.

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