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Thermal Effect on the Flexural Performance of Lightweight Reinforced Concrete Beams Using Expanded Polystyrene Beads and Pozzolana Aggregate

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Abstract

The innovation involved in the utilization of Expanded Polystyrene Beads (EPS) is found in its transformative effect on conventional concrete practices. By integrating EPS beads into concrete mixes, a fresh and unique methodology emerges, resulting in a notable modification of the material's properties and the creation of new possibilities for construction and design. Investigating the bending characteristics of Reinforced Concrete (RC) beams containing EPS beads is crucial for progressing our understanding, refining design methodologies, ensuring structural soundness, and endorsing the proficient and conscientious adoption of innovative materials in the construction sector. This research undertook a practical exploration of how the utilization of EPS beads in conjunction with Pozzolana aggregate (PA) influences the flexural behavior of RC beams. A total of twenty-seven simply supported rectangular RC beams were cast, utilizing three distinct and innovative mixtures, and then subjected to two-point load testing until reaching the point of failure. These three mixtures were categorized as follows: a control mix, a mix incorporating only EPS, and a mix combining EPS with superplasticizer. The point of ultimate failure load was determined through experimental tests for all specimens, and the effect of temperatures (300 °C and 600 °C) on the RC beams containing EPS was also investigated. The results indicated that incorporating EPS and EPS with superplasticizers led to a decrease in both concrete compressive strength and density, with reductions of approximately 29.5% 21.6%, and 11.1% and 15.7% respectively. Furthermore, the inclusion of EPS significantly decreased the ultimate flexural capacity of the beams by around 23.9% compared to the control beams. However, the addition of a superplasticizer with EPS partially mitigated this reduction in capacity. Conversely, beams exposed to 300 °C demonstrated comparable capacity to the unheated control beams, while at 600 °C, a noticeable decline in ultimate load capacity was observed in comparison to the control beams.

Keywords: Pozzolana Aggregate; Expanded polystyrene beads; Heat effect; Flexural strength; Superplasticizer.
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1. Introduction

In many structural applications concrete is the most widespread material used in the construction industry. A unique feature of concrete that makes it a multilateral is that it consists of a group of materials with a wide range in density, durability, and strength properties. It can be produced from a considerable number of components, in many approaches for several applications.[1] Lightweight concrete (LWC) is a functional material for several structural applications that offers environmental, technical, and economical enhancement therefore in the new millennium it is intended to become a predominant construction material.[2–6] LWC is known for its advantages in the reduction of dead load of the structure, and area of the sectional members, facilitating the construction industry. It is used in many structural applications such as high-rise buildings and long-span bridges, therefore, decreasing the costs of construction.[7–10] Expanded polystyrene (EPS) is a type of stable non-absorbent low-density foam of closed-cell nature, consisting of separated air voids in a polymer matrix. It can easily be included in concrete to produce LWC of different densities for many structural components.[11–16] Chen and Liu[17] conducted an experimental

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study to provide extra data on the influence of foam material on the mechanical characteristics, workability, and thermal accessibility of EPS by partial replacement of EPS with foam. They found that a suitable replacement of EPS with foam improved the strength, thermal accessibility, and workability of EPS foamed concrete with densities in fresh conditions of 400 kg/m3 and 800 kg/m3 were manufactured, also under compressive load foamed EPS had a high absorption capacity. Sabaa and Ravindrarajah[18] carried out an experimental procedure to investigate the properties of lightweight concrete produced by replacing the coarse aggregate in a normal-weight concrete mixture with crushed chemically coated expanded polystyrene granules. The replacement values of coarse aggregate were 30%, 50%, and 70% to product LWC with densities ranging from 1600 to 2000kg/m^3. The results showed that with the reduction in the density of the EPS concrete mixture, the compressive strength and modulus of elasticity decreased whereas the creep coefficient and shrinkage of concrete increased. Prasittisopin *et al*.[19] analyzed the behavior of lightweight concrete produced by replacing both coarse and fine aggregate in a normal-weight concrete mixture with a specific percentage of EPS. Workability, mechanical characteristics, and long-term behavior were studied. Furthermore, the practical uses such as thermal, moisture, and sound isolation were also briefed. The test results showed that including EPS in a concrete mixture reduces the self-weight of the structural elements and provides thermal and sound insulation. Adding fly ash, fibers, and silica fume, improves the behavior of concrete, whereas deterioration of the strength by increasing the quantity of EPS due to high porosity, and for long-term performance of EPS in the concrete mixture adding of EPS gave positive effects on fire resistance and corrosion. Khatib *et al*.[20] established an experimental program to explore the flexural behavior of reinforced concrete (RC) beams made of foamed glass lightweight concrete by replacing a part of normal coarse aggregate with foamed They found that the increase in foamed glass volume produces lower compressive strength and density of concrete, also the flexural capacity and the cracking load of foamed glass RC beams were increased. Enhancement in ductility and higher deflection at failure were noted. Wu *et al*.[21] investigated the flexural behavior of RC beams made using both normal and lightweight concrete. Fine sediments collected from Shih-Men Reservoir were used as lightweight aggregates to produce LWC. The results showed that the mode of failure and load capacity of beams made with both lightweight and normal-weight concrete were the same whereas the maximum deflection and ductility of LWC were larger. Mohammed and Aayeel[22] conducted an experimental program to explore the flexural strength, failure mode, and crack pattern of RC beams made by replacing a specific percentage of coarse aggregate with recycled expanded polystyrene (EPS). The recycled expanded polystyrene concrete was produced by substituting 0%, 15%, 20%, 25%, 35%, 45%, or 60% of coarse aggregate volume with recycled EPS. The findings of the test indicated a reduction in splitting tensile strength, compressive strength, and modulus of rupture as the EPS volume percentage increased. An increase in beam stiffness and the cracking failure of recycled expanded polystyrene concrete were found. Also, the beam can resist applied load with acceptable levels compared with the ACI code. Khatib *et al*.[23] tested the flexural performance of RC beams produced by replacing sand fine aggregates with expanded glass. The replacement levels were 0%, 25%, 50%and 100% by volume with expanded glass. They found that the density and the compressive strength of concrete decreased as the percentage of expanded glass increased. Also, the ductility of concrete with expanded glass was enhanced. Tan *et al*.[24] carried out an experimental procedure to explore the flexural performance of lightweight foamed concrete beams compared to normal-weight concrete beams. They found a reduction in the ultimate load capacity of foamed LWC beams in comparison with normal-weight concrete beams while an increase in the deflection of foamed LWC beams in compassion with normal-weight concrete beams. Abdel-Jaber *et al*.[25] conducted an experimental investigation on rectangular RC beams to examine the impact of incorporating EPS beads and Pozzolana aggregate (PA) on shear performance.

A set of twenty-seven beams were cast utilizing three different mix designs; a control mix, a mix containing only EPS, and a mix comprising EPS along with an additive. The results demonstrated a decrease in both concrete compressive strength and density for beams that contained EPS only, with reductions of 21.7% and 24.9%, and for beams containing EPS with superplasticizers, with reductions of 11.3% and 16.2%, respectively. In contrast, beams subjected to a temperature of 300 °C demonstrated nearly the load capacity as the unheated control beams, and at 600 °C, the beams exhibited a significant reduction in their load-carrying capacity compared to the unheated control ones. Discovering innovative materials for concrete production that meet design criteria and demonstrate efficacy as construction materials has become imperative due to the escalating expenses associated with construction materials and the depletion of natural resources. This investigation proposes the incorporation of EPS beads as a partial substitute for lightweight pozzolana aggregate within concrete mixes. The bending characteristics of RC beams containing EPS beads have been overlooked in prior research, highlighting the significance of conducting this study. The purpose of this study is to assess the flexural behavior of LWC beams that have been constructed using varying volumes of EPS. The twenty-seven beams subjected to testing are divided into three distinct groups. Each group comprises three beams categorized as follows: The initial group comprises three lightweight RC beams. One of these beams was designed as a control, wherein the coarse mineral aggregate was completely substituted with coarse pozzolana aggregate (CPA). The second beam utilized CPA with a partial substitution of approximately 12.5% of CPA and 25% of fine aggregate (FA) with EPS. The third beam employed CPA and included a partial substitution of about 12.5% of CPA and 25% of FA, along with the addition of 250 ml of admixtures (specifically, superplasticizer). The second and third groups were designed in a manner similar to the first group, with the added factor of being subjected to elevated temperatures of 300°C and 600°C for the second and third groups, respectively.

2. Methodology

2.1 Material characteristics

2.1.1 Cement

The research employed Ordinary Portland Cement (OPC) Type I as the cement variety. The chemical composition of OPC Type I, as provided by the supplier, is presented in Table 1.

Table 1. The chemical components for the OPC.

Ingredients	CaO	Al_2O_3	SO_3	SiO_2	MgO	Fe_2O_3
Percentage (%)	62.5	5.5	1.9	21	2	3.2

2.1.2 Aggregate

In this practical examination, the standard coarse aggregate in the concrete mixture was substituted with coarse pozzolana aggregate (CPA) to explore how the utilization of lightweight aggregates (LWA) impacts the flexural characteristics of the RC structures. Various variations of the CPA's gradations were applied within the range of 4.75mm to 25mm. The aggregate's density, specific gravity, and water absorption characteristics were established following the guidelines specified in ASTM C127[26] tests. The attributes of the CPA are outlined in Table 2.

Table 2. Pozzolana aggregate properties.

Property	Water Absorption (%)	Density (kg/m^3)	Apparent Specific Gravity (ASG)
	1.44	1338	2.1

2.1.3 Expanded Polystyrene Beads (EPS)

As depicted in Fig. 1, the EPS utilized in this research was characterized by a white color and took the form of medium-sized circular particles with a diameter of approximately 4.5 mm. The manufacturer's specifications provide the Physical and Mechanical Characteristics of EPS, which are outlined in detail in Table 3.

2.1.4 Master Glenium 51

In this investigation, Master Glenium 51 was employed. This compound belongs to the Polycarboxylic family and is classified as a superplasticizer. The primary aim behind its incorporation into the mixture design is to optimize the distribution of cement particles, thereby improving its efficacy. The supplier's information regarding the attributes of Master Glenium 51 is presented in detail in Table 4.

Table 3. Physical and Mechanical Characteristics of EPS.

Physical Characteristics	
Density	0.00310 - 3.50 g/cc
Water Absorption	0.0300 - 9.00 %
Viscosity	1.65 - 1.70 cP
Permeability	0.500 - 3.50
Mechanical Characteristics	
Tensile Strength, Yield	47.1 - 51.0 MPa
Flexural Yield Strength	0.0750 - 3.00 MPa
Modulus of Elasticity	0.00650 - 2.65 GPa
Adhesive Bond Strength	0.100 - 0.400 MPa

Table 4. Superplasticizer properties.

Master Glenium 51 characteristics	
Appearance	Yellowish Brown liquid
pH-value	6.0 ± 1
Chloride content (%)	≤ 0.10 (by mass)
Alkali content (%)	≤ 5.0 (by mass)
Water reduction	≥ 112% of Reference mix
Specific gravity @ 20°C	1.10 ± 0.03 g/cm^3

Fig. 1 Expanded polystyrene beads.

2.1.5 Mixture proportions

For this empirical investigation, three distinct concrete mixes were created. The variations among these mixes revolved around the quantity of EPS and superplasticizers included in each batch. After several experimentation rounds, and as indicated by Alhnifat *et al.*[27] the most effective proportions for EPS were determined to be 12.5% of the coarse aggregate (CA) and 25% of the fine aggregate (FA), with volume-based partial replacement. This substitution was paired with the addition of 250 ml of superplasticizer. The specifics of the mixture proportions for each batch are elaborated upon in Table 5.

As indicated in Table 5, Mix 1 represents the control mix. In this mixture, the primary constituent is CPA, devoid of both EPS and any supplementary elements. Mix 2 encompasses CPA along with partial substitution of 12.5% CA + 25% FA for EPS. Lastly, Mix 3 includes the ingredients of Mix 2, with the further inclusion of 250ml of superplasticizer.

Table 5. Details of the mix proportions.

	Concrete Mixtures		
Ingredients	Mix 1	Mix 2	Mix 3
Cement /OPC (kg/m^3)	440	440	440
Coarse pozzolana aggregate (kg/m^3)	890	780	780
Fine aggregate (kg/m^3)	812	610	610
Superplasticizer (L/m3)	-	-	4.25
Expanded Polystyrene Beads (replaced by volume)	-	12.5% of the CA and 25% of the FA	
W/C *eff*	0.57	0.55	0.55

2.1.6 Reinforcing steel

The steel reinforcement utilized in the experimental phase consisted of deformed steel bars. These bars had an average yield strength of 420 MPa for longitudinal bars and 280 MPa for transverse bars, respectively.

2.2 Tested beams

2.2.1 Geometric characteristics and reinforcement specifications

To assess the impact of incorporating LWA alongside EPS on the flexural performance of RC beams, a total of twenty-seven RC beams with a simply supported configuration were constructed and designed to undergo flexural failure. Geometric characteristics and reinforcement specifications for the RC beams are depicted in Fig. 2.

2.2.2 Test matrix

Twenty-seven RC beams, characterized by a simply supported rectangular shape, were divided into three primary testing categories, differentiated by their concrete mix composition and exposure to heat-induced conditions. Group A encompassed three specimens, each designed with distinct concrete mixes. The initial specimen, labeled LF, acted as the control beam and followed the Mix 1 composition. The second specimen, denoted as LF-P, incorporated a partial replacement of EPS by volume, adhering to the Mix 2 proportions. Lastly, the third specimen, named LF-P*, combined EPS and superplasticizer in accordance with the Mix 3 specifications. Both Group B and Group C featured three specimens, akin to those in Group A. However, a significant distinction lay in subjecting the specimens to temperatures of 300 °C and 600 °C for Group B and Group C, respectively. Table 6

Table 6. Test matrix.

Group ID	Beams Designation		Mix Type*
Group A	1	LF	Mix 1
	2		
	3		
	1	LF-P	Mix 2
	2		
	3		
	1	LF-P*	Mix 3
	2		
	3		
Group B	1	LF 300	Mix 1
	2		
	3		
	1	LF-P 300	Mix 2
	2		
	3		
	1	LF-P* 300	Mix 3
	2		
	3		
Group C	1	LF 600	Mix 1
	2		
	3		
	1	LF-P 600	Mix 2
	2		
	3		
	1	LF-P* 600	Mix 3
	2		
	3		

* Mix1 contains LWA but does not include EPS or any additives. Mix2 includes both LWA and EPS but does not contain any additives. Mix3 combines LWA with EPS and includes additives.

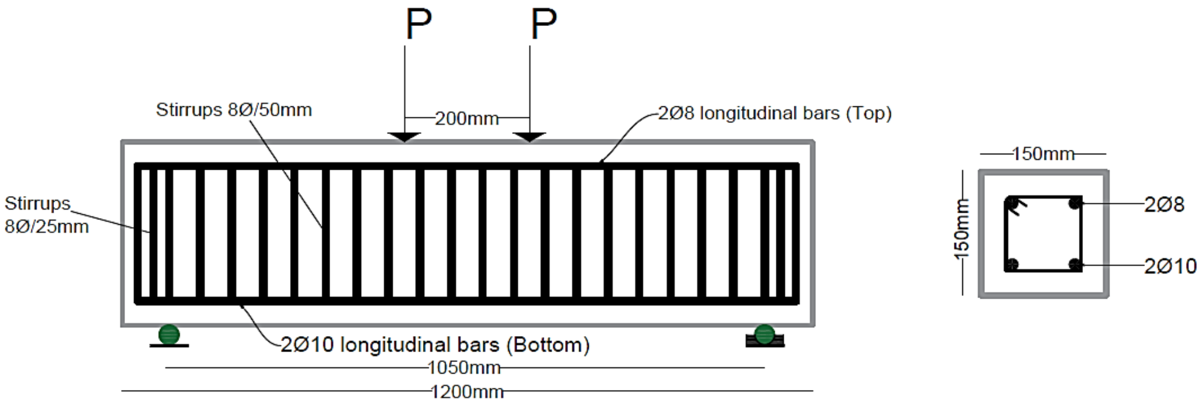

Fig. 2 Geometric characteristics and reinforcement specifications.

presents a visual representation of the test matrix. The nomenclature employed for the specimen names carries the following meanings: L for Lightweight Aggregates (LWA); F for flexural reinforcement; P for Expanded Polystyrene (EPS); * to indicate an additive; and the temperature values 300-600 to signify exposure temperatures.

2.2.3 Test setup

The examined beams underwent a four-point bending assessment until reaching the point of failure. The testing apparatus used, labeled ADR-Auto and capable of bearing loads up to 2000 kN, is depicted in Fig. 3. A consistent loading rate was employed, and the displacement measurements were captured at intervals of 1 kN. To measure deformation, three strain gauges were affixed to the bottom of each specimen: one at the mid-span and the remaining two at the quarter from both left and right sides.

2.3 Casting and curing of beams

This investigation involved the creation of a total of twenty-seven beam specimens and an equal number of standard cubes to examine various properties. The cube dimensions measured 150x150x150 mm, while the beam dimensions stood at 150x150x1150 mm. The production process included the preparation of three distinct concrete mixtures utilizing a mechanical tilting drum mixer. The concrete placement occurred in three distinct layers, with each layer being compacted through 35 strokes according to ASTM C192 standards.[28] A trowel was employed to achieve a level surface, following which the beam and cube samples were retained within the molds for a period of one day. Subsequently, they were transferred to water tanks maintained at temperatures ranging between 23°C and 25°C, initiating a 28-day curing process. The procedure's progression is illustrated in Fig. 4.

2.4 Application of heat

The beams were subjected to heat treatment within a furnace, as illustrated in Fig. 5. The furnace possessed specific dimensions measuring 2 m length, 2.5 m width, and 0.8 m height. To manage the temperature and duration, a control panel for heating regulation was integrated with the furnace. In total, eighteen beam specimens were subjected to a heat treatment lasting for a duration of 2 hours. Within this set, nine beams were subjected to a temperature of 300 °C, while the remaining nine beams underwent exposure to 600 °C. The primary aim was to investigate the influence of heat on the flexural attributes of three types of beams: control beams, beams only comprised of EPS beads, and beams constructed using both EPS beads and an additive.

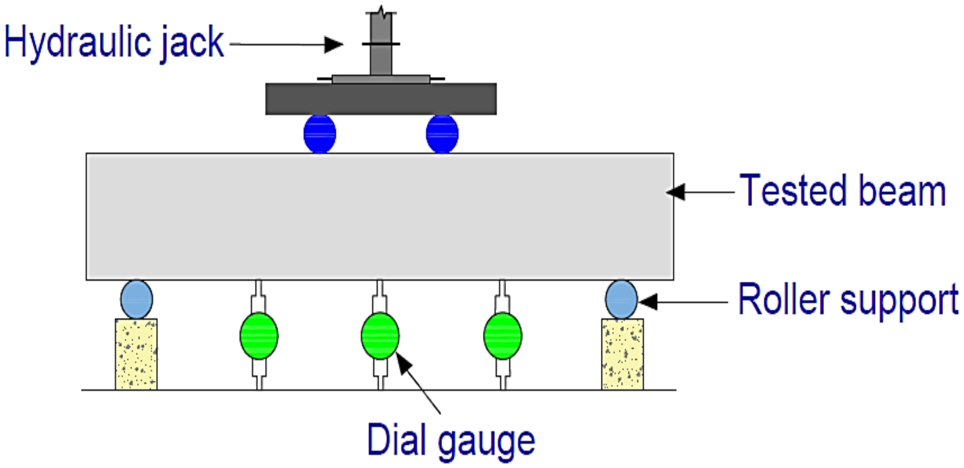

Fig. 3 Test setup.

Fig. 4 Casting of beams and cubes.

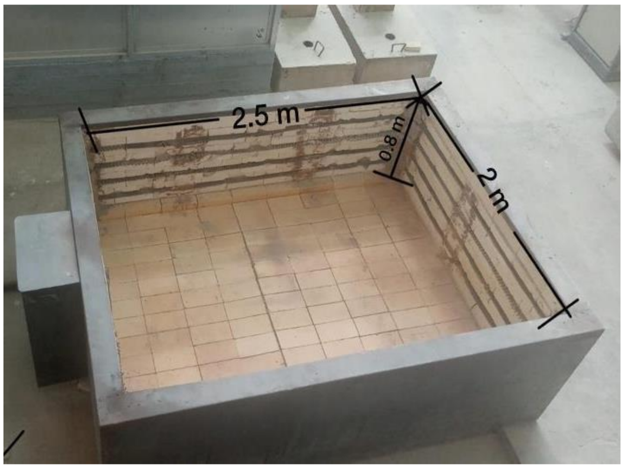

Fig. 5 Furnace size.

3. Results and discussion

3.1 Concrete compressive strength

The compressive strength of various concrete mix designs was assessed by testing a total of twenty-seven concrete cubes. The outcomes, which include the average compressive strength values for both cubic and cylindrical specimens, are presented in Table 7.

Table 7. Concrete compressive strength values.

Concrete Mix	Average Cubic Concrete Compressive Strength (MPa)	Average Cylindrical* Concrete Compressive Strength (MPa)
Mix 1	34.7	27.8
Mix 2	24.5	19.6
Mix 3	27.2	21.8

*f_c'(cylinder)= 0.8 f_c (cube)

As indicated in Table 7, Mix 1 exhibited an average cylindrical compressive strength of 27.8 MPa without the incorporation of EPS and superplasticizer. In the case of Mix 2, wherein 12.5% of CA and 25% of FA were replaced with EPS, the concrete strength dropped to 19.6 MPa. Meanwhile, Mix 3, which included both EPS and superplasticizer, achieved a strength of 21.8 MPa. Notably, the replacement of 12.5% CA and 25% FA with EPS resulted in a notable reduction in concrete strength. It's worth highlighting that the presence of superplasticizer played a significant role in mitigating the decline in concrete strength. The reduction in compressive strength was 29.5% for Mix 2 and 21.6% for Mix 3, respectively.

In conclusion, the introduction of EPS beads into the mixture had a negative impact on the mixing process and the bond between cement and aggregate. Additionally, the incorporation of EPS beads led to the partial replacement of denser aggregates within the concrete mixture, contributing to an overall decrease in the compressive strength of the concrete.

3.2 Concrete density

Concrete density values for each concrete mix design are presented in Table 8.

Table 8. Concrete mixes densities.

Mix	Concrete Density (kg/m^3)	Reduction (%)
Mix 1	2223	-
Mix 2	1976	11.1%
Mix 3	1875	15.7%

According to the data in Table 8, the concrete densities for the three distinct mixes were recorded as follows: 2223 kg/m^3 for Mix 1, 1976 kg/m^3 for Mix 2, and 1875 kg/m^3 for Mix 3. It is evident that both Mix 2 and Mix 3 exhibited lower concrete densities compared to the control mix, Mix 1. Notably, both Mix 2 and Mix 3 incorporated EPS at rates of 12.5% of CA and 25% of FA. This highlights the significant role of EPS in decreasing concrete density. Furthermore, the percentage reduction in density amounted to 11.1% for Mix 2 and 15.7% for Mix 3, suggesting that the combination of EPS and superplasticizer in Mix 3 was particularly effective in reducing the concrete density.

3.3 Experimental flexural behavior

Table 9 presents the outcomes of the experiments, encompassing data on factors of ultimate failure load, concrete

Table 9. Test results.

Group ID	Samples	Cubic Compressive Strength f_{cu} (MPa)	Ultimate Failure Load, Pu (kN)	Average Ultimate Failure Load, Pu (kN)	Ultimate Deflection (mm)	Average Change % in Pu
Group A	LF 1	34.7	61	62.2	7.4	-
	LF 2	32.5	63.7		7.8	
	LF 3	36.8	62		6.5	
	LF-P 1	24.5	46.7	47.3	4.85	-23.9
	LF-P 2	27.2	49.2		5.9	
	LF-P 3	21.8	46		5.5	
	LF-P* 1	27.2	59	59.6	7.9	-4.2
	LF-P* 2	29.1	61		8.2	
	LF-P* 3	25.2	58.9		8.8	
Group B	LF 300 1	32.3	60.6	62.3	8	-
	LF 300 2	31.7	64		8.8	
	LF 300 3	32.9	62.4		8.5	
	LF-P 300 1	25.3	47	48	6.4	-22.9
	LF-P 300 2	28.6	48.8		5.8	
	LF-P 300 3	22	48.1		7	
	LF-P* 300 1	25.6	59.8	60.1	8.4	-3.5
	LF-P* 300 2	25.9	61.4		8.6	
	LF-P* 300 3	25.3	59.1		7	
Group C	LF 600 1	23.4	54.5	54.3	7.4	-
	LF 600 2	24.6	55.8		7	
	LF 600 3	22.3	52.6		7.5	
	LF-P 600 1	21.4	44.7	42.4	7.85	-28.7
	LF-P 600 2	26	41.9		7	
	LF-P 600 3	16.7	40.6		8.3	
	LF-P* 600 1	23.7	53.5	53.6	7.2	-1.3
	LF-P* 600 2	22.2	54.4		7	
	LF-P* 600 3	25.4	52.8		6.9	

compressive strength, and maximum deflection at the mid-span, all of which pertain to twenty-seven beams. This section provides an analysis of the test findings, focusing on load-deflection curves, the load-carrying capacity, and the manner in which failures occurred.

Initially, the outcomes related to Group A highlight that the introduction of EPS beads into the concrete mixture of beams led to a 23.9% reduction in the load-bearing capacity when compared to the control beams. This decrease was attributed to the weak bond between EPS and cement, as well as EPS's notable compressibility and low elastic modulus.[22] In contrast, beams containing both EPS beads and a superplasticizer exhibited a load-carrying capacity nearly equivalent to that of the control beams. This similarity indicates the effectiveness of incorporating EPS beads and a superplasticizer into the concrete mixture, achieving comparable behavior and load-bearing capabilities to the control mix. The superplasticizer played a role in enhancing the adhesive interaction between polystyrene particles.[22] Refer to Fig. 6 for the load-deflection curves, depicting the behavior of specimens LF, LF-P, and LF-P* respectively. Fig. 7 presents the failure load for beams in group A. In the case of Group B, beams cast with a concrete mixture containing EPS beads and then subjected to a temperature of 300 °C exhibited a 22.9% decline in their load-carrying capacity in comparison to control beams that experienced the same level of heat exposure. Conversely, beams incorporating both EPS beads and a superplasticizer, and then heated to the same temperature, displayed a load-carrying capacity almost identical to the control beams. This behavior can be attributed to the hydration process, which leads to the swift formation of cementitious compounds and consequently an elevation in the strength of the concrete.[29] Fig. 8 visually presents the load-deflection patterns of specimens heated to 300 °C, namely LF300, LF-P300, and LF-P*300. Fig. 9 shows the failure load for beams in group B. A decrease of 28.7% in load-carrying capacity was observed in beams that integrated EPS beads into their mixture and were subsequently exposed to a temperature of 600 °C, compared to heated control beams within the same category (Group C). However, beams containing both EPS beads and a superplasticizer exhibited a load-carrying capacity similar to that of heated control beams subjected to the same high temperature. The increase in temperature causes thermal expansion in concrete, resulting in its expansion. This expansion, in turn, induces internal stresses, leading to potential cracking, spalling, and detachment of the concrete surface. Such fractures and separations contribute to the weakening of the beam's structural integrity, consequently diminishing its ability to endure loads. Moreover, elevated temperatures can lead to a weakening or even breaking of the bond between the concrete matrix and the reinforcing steel. This weakened bond hampers the effective transfer of loads between the steel reinforcement and the concrete, ultimately influencing the overall strength of the beam. Fig. 10 visually depicts the load-deflection characteristics of specimens LF600, LF-P600, and LF-P*600 within Group C. The observed reduction in load-carrying capacity for beams exposed to 600 °C indicates a degradation in the mechanical properties of the beams at this temperature.[30,31] Fig. 11 illustrates the failure load for beams in group C.

3.4 Failure mechanisms

In this experimental test, the failure mode for all beam specimens was a flexural failure. The cracks monitored for all specimens showed approximately the same behavior. Cracks gradually developed along the tension side of the beam starting from the bottom. These cracks propagated and widened, indicating the redistribution of stresses within the concrete. Eventually, the cracks coalesced, leading to a critical crack that significantly weakens the beam's cross-section. At this stage, the concrete on the tension side lost its load-bearing capacity, and the steel reinforcement began to bear a greater portion of the load. The deformation became more pronounced, and the beam's deflection increased rapidly. When the beams reached their ultimate capacity, a ductile flexural failure occurred. Fig. 12 shows the mode of failure for all beams.

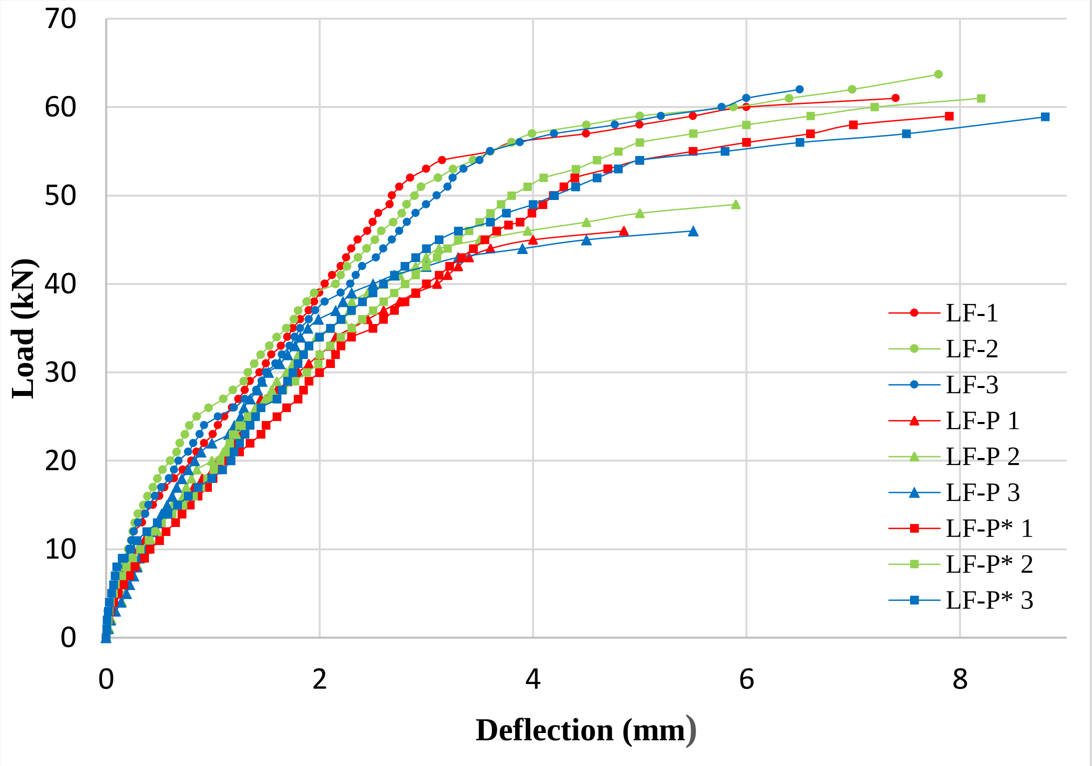

Fig. 6 Load-deflection curves for Group A.

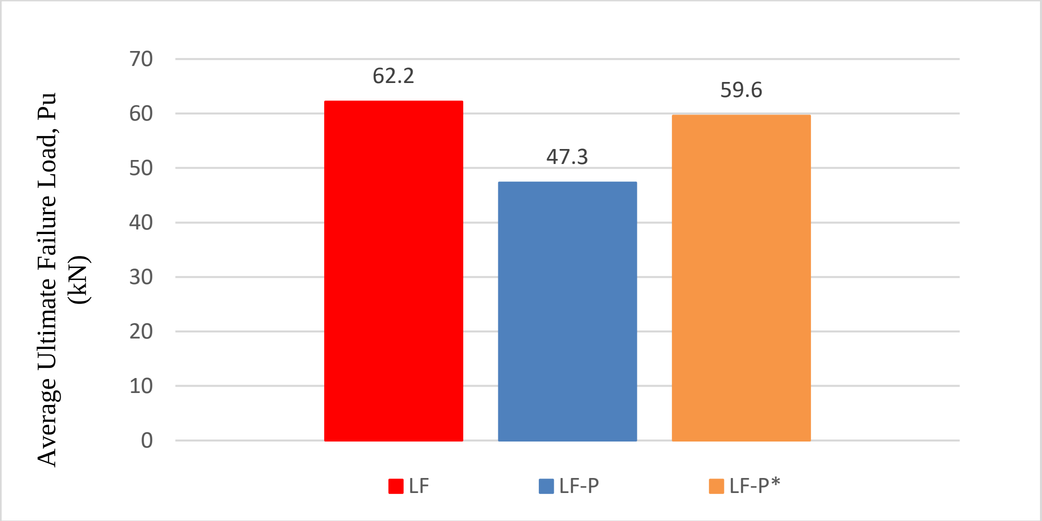

Fig. 7 Failure load for beams in group A.

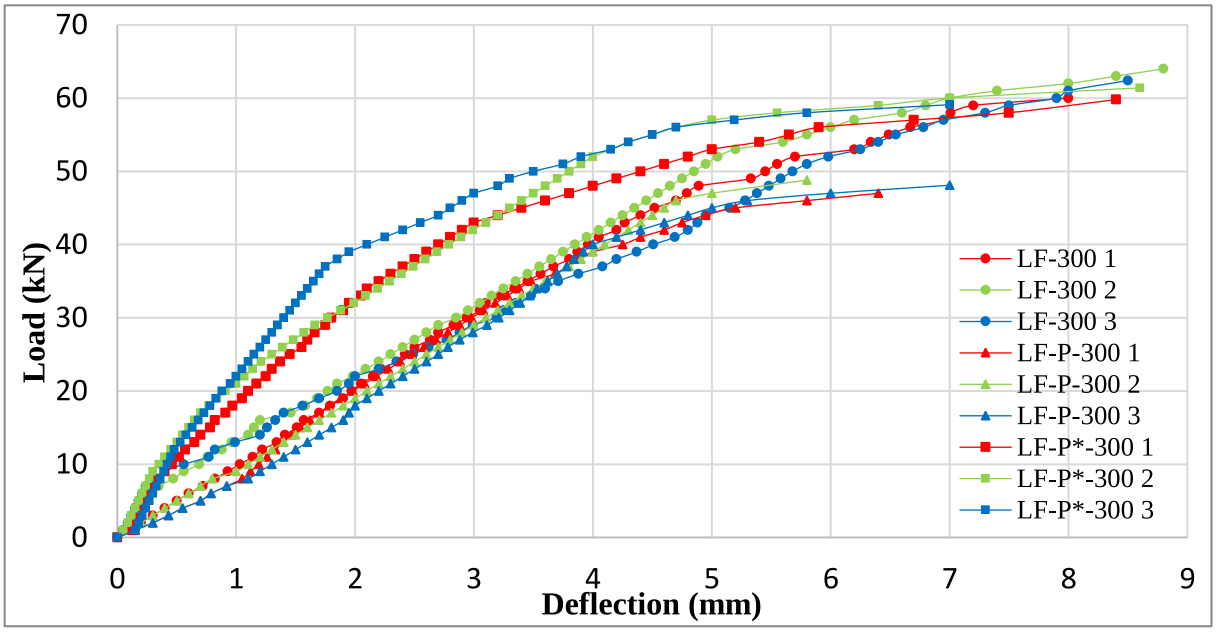

Fig. 8 Load-deflection curves for Group B.

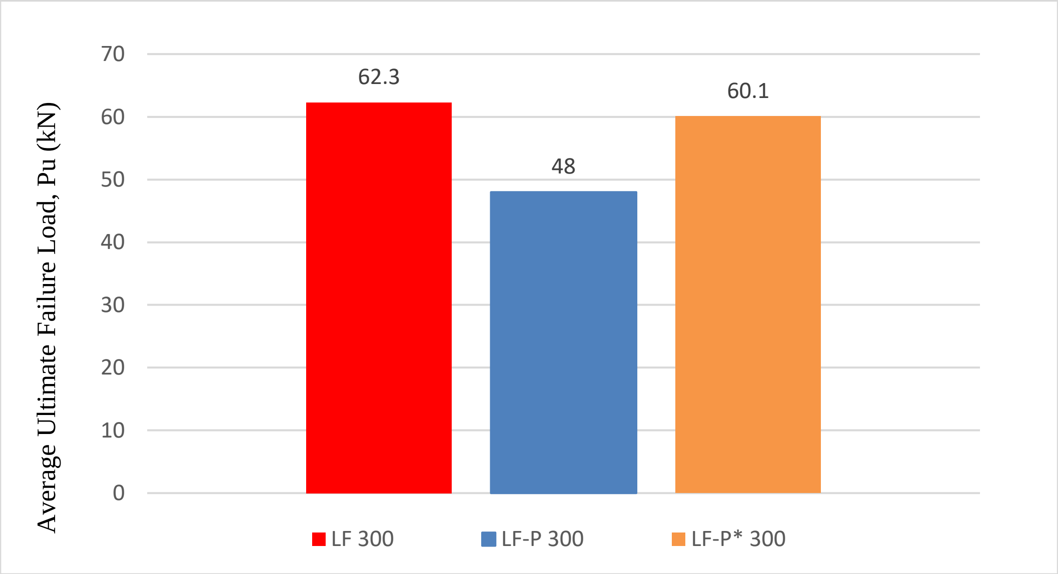

Fig. 9 Failure load for beams in group B.

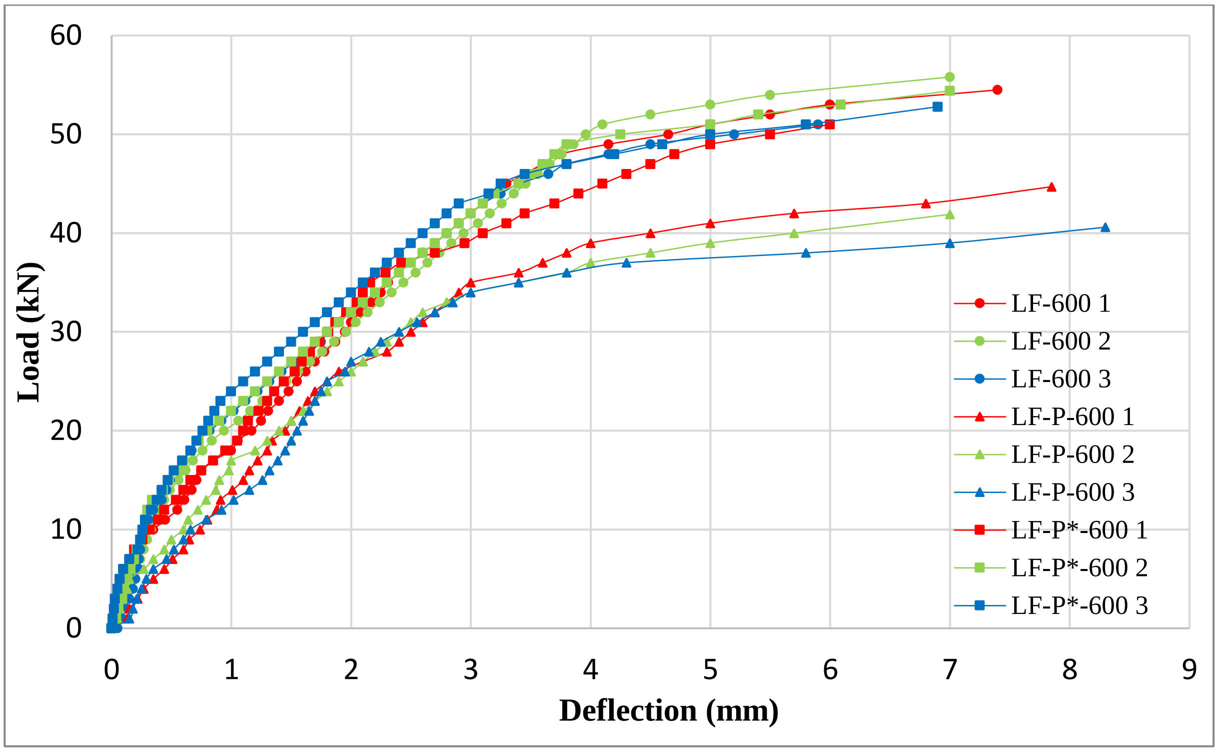

Fig. 10 Load-deflection curves for Group C.

3.5 Effect of high temperatures

As per the outcomes of the experiments, the ultimate load-carrying capacity of RC beams decreased notably when they were subjected to high temperatures (600 °C). This exposure led to a considerable degradation in the structural integrity of the beams. Notably, the EPS material present in the concrete cover region underwent evaporation due to the impact of heat, which was observed both at 300 °C and 600 °C. However, the EPS material within the RC beams remained unaffected by evaporation. Fig. 13 visually demonstrates the difference between the presence of EPS on the concrete surface and its absence of evaporation within the beams themselves. EPS beads tend to evaporate at the concrete cover, particularly at elevated temperatures, due to their location and exposure to the external environment. The concrete cover is the outermost layer of the RC element and is directly exposed to the surrounding heat and conditions. When RC beams are subjected to elevated temperatures, such as high temperatures, the heat affects the EPS beads primarily through evaporation mechanisms. EPS beads are made of expanded polystyrene, which is a cellular plastic material containing air-filled voids, when exposed to high temperatures, these voids can heat up and cause the air inside them to expand. This expansion can lead to the beads losing their structural integrity, and the air can escape, causing the beads to evaporate. The EPS beads inside the beam are surrounded by concrete, which acts as

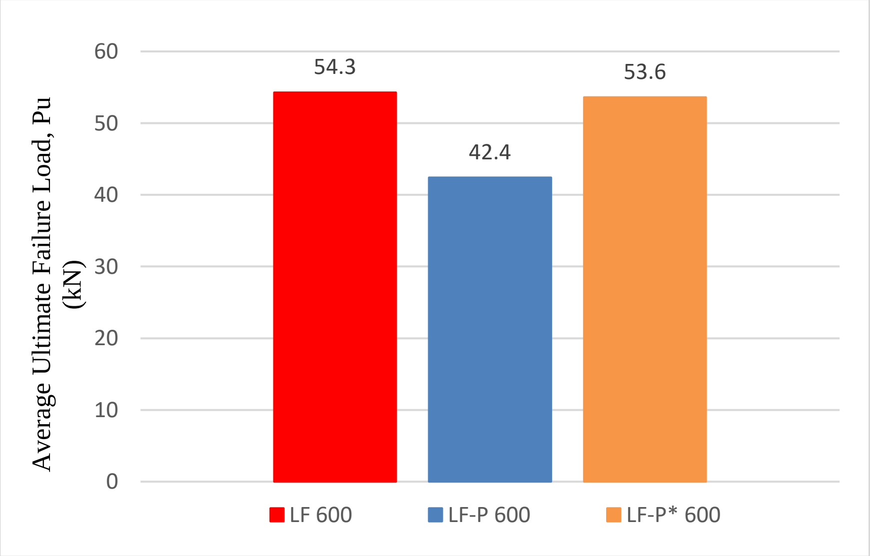

Fig. 11 Failure load for beams in group C.

Fig. 12 Crack patterns of tested beams.

insulation and slows down the transfer of heat to the EPS beads. This insulation effect can prevent the beads from reaching temperatures high enough to trigger evaporation.

4. Sustainable and energy-effective design considerations

Within the contemporary context of heightened attention to sustainable and energy-efficient construction practices, this section delves into the broader ramifications inherent in the adoption of lightweight reinforced concrete beams incorporating pozzolana aggregate and expanded polystyrene beads. The investigation extends beyond mere structural performance, delving into the ecological footprint reduction potential of these innovative materials. Specifically, the study scrutinizes the possibility of curbing embodied carbon

Fig. 13 The influence of temperature on EPS beads on the surface and inside the RC beams.

emissions, diminishing overall energy consumption, and mitigating environmental impacts. Moreover, it ventures into the realm of improved thermal attributes inherent in such concrete compositions. This enhancement in thermal behavior not only augments occupants' indoor comfort but also engenders a pronounced decrease in energy requisites within constructed spaces. By underpinning sustainability objectives and ushering in energy efficiency gains, this research elucidates the confluence of material innovation and ecological consciousness in shaping the construction landscape of the future. In commercial structures, where large spans and load-bearing capacities are essential, the utilization of these innovative materials in beams and slabs can lead to decreased dead loads on the foundation and structural elements. This weight reduction not only optimizes material usage but also allows for more efficient structural designs, ultimately contributing to reduced resource consumption during construction. The presence of EPS beads within a concrete mix can contribute to maintaining more consistent indoor temperatures in buildings. EPS beads are known for their excellent thermal insulation properties, which can help regulate heat transfer through walls and floors. Overall, the thermal insulating properties of EPS beads in concrete contribute to the positive management of indoor temperatures, making buildings more energy-efficient and conducive to a comfortable living environment.

5. Conclusion

A comprehensive experiment was conducted to examine the influence of incorporating EPS beads and Pozzolana aggregate on the flexural performance of reinforced concrete (RC) beams. The investigation involved casting twenty-seven rectangular simply supported beams. These beams were cast using three distinct mix designs and subjected to two-point load testing until failure. The mixes were categorized as follows: the control mix, a mix containing only EPS beads, and a mix containing both EPS beads and an additive. The experimental study included the measurement of the ultimate failure load for all specimens, along with an assessment of the impact of elevated temperatures (300 and 600 °C) on the behavior of the EPS RC beams. The study's findings can be summarized as follows:

1. Adding 12.5% of CA and 25% of FA along with EPS beads significantly decreased concrete strength by 29.5%. When 250 ml of superplasticizer was added to this mix, the reduction was 21.6%. Including lightweight EPS beads displaces denser aggregates, affecting strength. It also disrupts even water and cement dispersion during mixing, impacting curing and bond formation in the concrete structure.
2. Adding EPS to concrete lowered its density by 11.1% without superplasticizer and 15.7% with it. EPS beads are much lighter than regular aggregates, making the concrete overall lighter. This lighter mix is easier to handle, transport, and place due to reduced component weight.
3.Beams exposed to 300 °C behaved similar to unheated beams. High temperature speeds up the concrete's chemical reactions, making it stronger by quickly creating cement-like compounds. The heat acts as an energy catalyst, enhancing the concrete's strength.
4. Beams exposed to 600 °C showed a significant drop in their ability to carry loads compared to unheated beams. This reduction is due to the deterioration of the beam structure's mechanical properties caused by high-temperature exposure.
5. When exposed to 300 °C, beams made only with EPS beads had a 22.9% reduction in load-bearing capacity compared to heated control beams. However, beams with a mix of EPS beads and a superplasticizer performed similarly to the heated control beams in terms of load-carrying capacity.
6. When exposed to 600 °C, beams made only with EPS beads had a 28.7% decrease in load-bearing capacity compared to the heated control beams. However, beams containing a mix of EPS beads and a superplasticizer showed only a slight reduction in load-carrying capacity, similar to the heated control beams.

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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