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THE BEHAVIOUR OF REINFORCED CONCRETE BEAMS BY USING EXPANDED POLYSTYRENE BEADS AND PALM OIL FUEL ASH AS REPLACEMENT MATERIALS

The Reinforced Concrete (RC) beams containing Expanded Polystyrene Beads (EPS) and Palm Oil Fuel Ash (POFA) as sand and cement replacement with a percentage between 10% and 30%were studied in terms of load-deflection behaviour. RC beam's size was 1000×150×150 mm and simply supported at spaced 750 mm apart. The 10% of POFA without EPS shows a slight increase which is 0.26% higher than normal concrete in compressive strength. The ultimate load and flexural performance of RC beams with EPS and POFA exhibited a decreasing trend. All beams' ultimate load exceeds the design value. The cracks of the RC beam may be classified as vertical flexural cracks, and some of the cracks can be classified as shear cracks based on the crack angle. As the percentage of EPS and POFA increases above 20% for all specimens, cracking starts to change to shear cracking.

Keywords: EPS; POFA; Compression; Flexural

1. Introduction

The common reinforced concrete (RC) beams are made of solid reinforced normal weight concrete. These RC beams are strong but costly, heavy and not environmental friendly. As such, a new lighter, better performance and environmental friendly RC beam or structure is needed to cater for such demand. Therefore expanded polystyrene beads (EPS) and Palm Oil Fuel Ash (POFA) are combined in RC beam.

Concrete is a man-made composite material. It consists of fine coarse aggregate, water and cement. Ordinary Portland cement is the most common one used in construction. As fine coarse aggregates are mixed with Portland cement and water, the mixtures will form a mortar that acts like half liquid half-solid state. So that it can be moulded easily and formed into a shape and performance according to structure demand. However, different types and ratios of concrete mixtures will be obtained with different strengths. The compressive strength of either a solid cube or a cylindrical specimen is used to determine the value of concrete strength.

Nowadays, there are numerous studies regarding new concrete produced by using recycled material to achieve certain workability and level of strength. POFA and EPS are some examples of waste materials that can produce lower-density concrete with similar performance to normal concrete in terms of strength. POFA is a substantial by-product of the palm oil industry and maybe visually viewed as a greyish colour. Many researchers have also concluded that it is capable of replacing cement because it is available in higher quantities and has the same binder characteristic as cement. On the other hand, EPS is a type of construction material that can improve a building's design and structural integrity. It is used in a variety of architectural structures due to its long-term benefits and improvements in energy efficiency, durability, and indoor temperature.

The concrete industry today poses a threat to global ecology, as it consumes vast amounts of natural resources while also emitting poisonous gases such as carbon dioxide [1]. Nonetheless, the cement manufacturing process consumes a lot of energy and, more significantly, emits a lot of greenhouse gases (GHG) into the atmosphere. In Malaysia, the issue of industrial waste, such as polystyrene, is getting worse. When polystyrene is burned, harmful gases are released into the atmosphere, polluting the environment [2].

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This study focused on investigating the ratio of EPS and POFA as an alternative material for sand and cement to sustain the flexural performance of the RC beam. The study also focuses on developing a lighter-density RC beam containing EPS and POFA which can comparable with a normal RC beam to withstand the load designed. This study's goals include comparing the compressive strength of concrete containing EPS and POFA to normal concrete, as well as looking at the flexural behaviour and deformation pattern of EPS and POFA reinforced concrete beams. The significance of the study is that concrete containing expanded EPS and POFA can minimize environmental pollution issues. It was also able to recycle the industrial waste that Malaysia has now with an environmental problem in disposing of POFA and EPS. Furthermore, the combination of EPS and POFA in concrete be may produce lighter density and compatible characteristic compared to normal concrete because the influence of those selected materials has much lower density and possess good pozzolanic properties.

2. Replacement material in concrete

2.1. Expanded polystyrene (EPS)

Expanded polystyrene as shown in Fig. 1 is a well-known insulation material that is utilised in a variety of applications due to its lightweight but stiff foam that provides good thermal insulation and significant impact resistance [3]. Since EPS is a synthetic ultra-lightweight aggregate with closed-cell membranes and is non-absorbent, it is an excellent material for the concrete industry [4]. In order to make lightweight concrete, low-density foam is encased in a durable polymer matrix, and polystyrene beads are embedded within mortar or concrete. When EPS is utilized as aggregates, the lightweight concrete is able to be stronger and lighter than normal lightweight concrete [3].

Fig. 1. Expanded Polystyrene Beads (EPS)

2.2. Palm oil fuel ash (POFA)

POFA is a relatively new addition to the pozzolanic ash family [5]. It is a byproduct of a biomass thermal power plant, where wastes from oil palms such palm oil husk and palm kernel shell are burnt to produce electricity at temperatures of 800-1000°C [6-8]. The colour of the ash produced might range from a pale grey to a darker shade of grey. POFA is generally grey and darkens as the fraction of unburned carbon increases. The particles are typically spherical and have a lower specific gravity than Ordinary Portland Cement (OPC), although having a wide variety of sizes [8]. POFA has a specific gravity of 2 to 2.5, which is less than OPC's specific gravity.

Fig. 2. Palm oil fuel ash (POFA)

3. Methodology

3.1. Beam specimens

Reinforced Concrete beam have been design base on Eurocode 2 which is may carry 30 kN point load at middle of beam. The beam size is 150 mm width × 150 mm depth and 1000 mm length . For reason on support all beams were simply supported on two rolling bearing spaced 750 mm Centre to centre. Three-point bending test had been implemented to examine flexural strength and deformations. Different EPS and POFA percentages are mixed with cement to form a concrete beam as shown in Fig. 3. The percentages used are 0%, 10%, 20% and 30% for EPS and 0% and 10% for POFA. The beam design required 2Y12–226 mm^2 for both compression and tension reinforcement. The link used is 12Y8–80 for this beam.

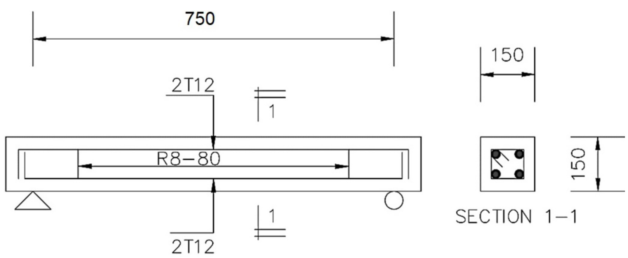

Fig. 3. The specimen of the beam

3.2. Concrete mix proportion and mixing

Sand, coarse aggregate, cement, water, POFA and EPS were the materials to be used in this experiment. Furthermore, grade 25 concrete was used for this study. The further calculation for the ratio of materials was using the method proposed by the Department of Environment (DoE), United Kingdom [9] as shown in TABLE 1

TABLE1

Concrete Mix Design Grade 25 (control)
(Normal concrete design mixes)

Water cement ratio	0.5
Cement	320 kg/m^3
Water	160 kg/m^3
Fine aggregate	405 kg/m^3
Coarse aggregate	1440 kg/m^3

3.3. Experimental

The beams were tested in the laboratory in UTHM Pagoh. The analysis is carried out through compressive test and flexural test.

3.3.1. Compression test

Compressive strength tests were performed on specimens that had been treated in a normal manner, which included full compaction and wet curing for 28 days, to get results that reflected the concrete's prospective quality. There is 2 type of compressive test which are the cube test and cylinder test. To conduct a cube test, BS EN 12390-1: 2000 recommends filling the mould in one or more layers and compacting the layers using a porker vibrating. After the mould is full, the specimen needs to be stored undisturbed for 16 to 72 hours before undergoingthe compressive test.

3.3.2. Flexural test

As shown in Fig. 4, a flexural test is performed on a reinforced concrete beam to determine its behaviour. The deflection test was performed based on the procedures prescribed in ASTM C 293. This test's main objective is to ascertain the relationship between a simply supported beam's loading and deflection under a point load.

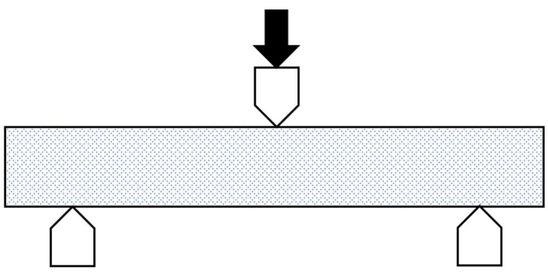

Fig. 4. Test setup for RC beam based on ASTM C293 [10]

4. Results and Discussions

4.1. Compressive strength test

A 100×100×100 mm cube sample was put through a compression test. The total number of cubes were 24 and were curing for 7 days and 28 days, respectively. The test was done based on the percentages of 0% POFA and 10% POFA with 0%, 10%, 20% and 30% of EPS

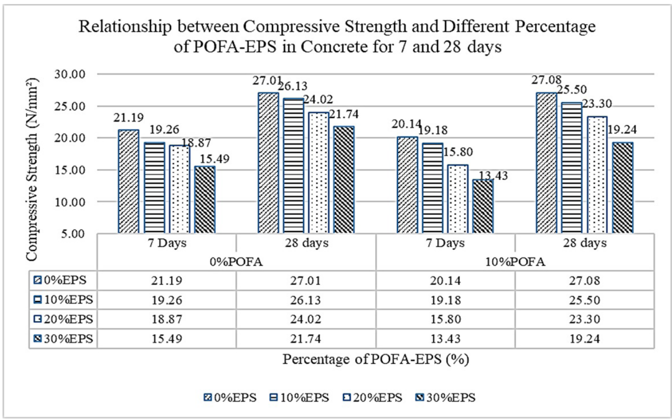

Fig. 5. Graph of average compressive strength for 7 and 28 days

As demonstrated in Fig. 5, the compressive strength is directly proportional to the curing age. A normal concrete cube's compressive strength was reported to be 21.19 MPa and 27.01 MPa, respectively, for 7 days and 28 days after curing. The compressive strength of concrete cube for 7 days and 28 days had reduced as the proportion of EPS increased from 10% to 30%. EPS with 10%, 20% and 30% combined with 0% POFA showed a strength of 26.13MPa, 24.02MPa and 21.74MPa, respectively, after 28 days. For 7 days, the concrete with 10%, 20%, and 30% EPS without POFA measured 19.26 MPa, 18.87 MPa, and 15.49 MPa, respectively. The concrete strength for 28 days of curing shows a 3.25%, 11.06% and 19.51% decrease with containing 10%, 20% and 30% EPS as the fine aggregate replacement without POFA. The compressive strength will be reduced by increasing the amount of EPS [2]. The major reason for the decline in strength brought on by adding more EPS aggregate might be because EPS is significantly weaker and less rigid than natural aggregates. A weak transition zone between the cement paste and the aggregate is also created when EPS is present in concrete. The concrete of 10% POFA without EPS shows a slight increase with gave 27.08 MPa which is higher compressive strength than those of normal, 20% and 30%. The percentage of concrete strength for 10% POFA was a 0.26% increase compared to normal concrete. This phenomena was most likely brought on by POFA's pozzolanic reaction, which gave concrete its strength. However, the strength of concrete with 20% and 30% POFA and 0% EPS after 28 days was measured at 25.8 MPa and 24.02 MPa, respectively, with strength declines of 7.14 and 11.06 %. So that from this study result, shows that the concrete containing POFA up to 10% without EPS can improve the compressive strength. As mention above, the POFA's pozzolanic action may have contributed to the rise in compressive strength.The compressive strength also showed is similar to OPC when 10% POFA is added to mixtures according to N. Liu and B. Chen [16]. Other results for concrete containing increasing POFA and increasing EPS show a decreasing trend, for concrete containing 10% POFA and 10% EPS indicating a compressive strength of 25.5 MPa is still greater than normal concrete. Meanwhile, concrete containing 30% POFA and 20% EPS possessed an 18.26 MPa compressive strength, which was still appropriate for use on building structures as indicated in ACI 213, which requires a minimum compressive strength of 2500 psi for structural concrete (17 MPa). As a consequence of the foregoing findings, 10-20% POFA and 10% EPS were found to be the optimal cement and fine aggregate replacement rates for concrete compressive strength, indicating that the compressive strength of the concrete was comparable to that of normal concrete.

4.2. Load capacity and displacement on RC beams

The maximum load capacity on the reinforced concrete beam decreased with the increase of the percentage of POFA and EPS based on Fig. 6 above. When 0% of POFA is used, the maximum load capacity on reinforced concrete beam with 0%, 10%, 20% and 30% of EPS is 143.23 kN, 142.7 kN, 137.07 kN and 136.47 kN respectively. Meanwhile, the maximum displacement also recorded for each RC beam with 0%, 10%, 20%, and 30% of EPS are 6.50 mm, 7.17 mm, 4.33 mm and 9.17 mm respectively. However, when 10% of POFA is added, the maximum load capacity for a reinforced concrete beam with 0%, 10%, 20% and 30% of EPS is recorded with 127.30 kN, 122.60 kN, 116.47 kN and 113.47 kN respectively. The maximum displacement was recorded at 5.67 mm, 11.33 mm, 5.67 mm and 5.83 mm respectively. Based on the result, the trend of the maximum load capacity is decreased as POFA and EPS are used. As the EPS volume percentage rises, the flexural strength of EPS concrete linearly falls [12]. Large EPS particles reduce the flexural section height, which leads to a drop in flexural strength. Furthermore, as compared to concrete specimens without POFA, adding POFA to any volume may decreased flexural strength. This could be linked to POFA's porous nature, this led to a buildup of tension and weakened the link between the paste and the aggregate [13]. All beams exhibited ultimate loads greater than the design value of 30 kN, despite the fact that the results of the flexural strength test indicated a tendency toward decline.

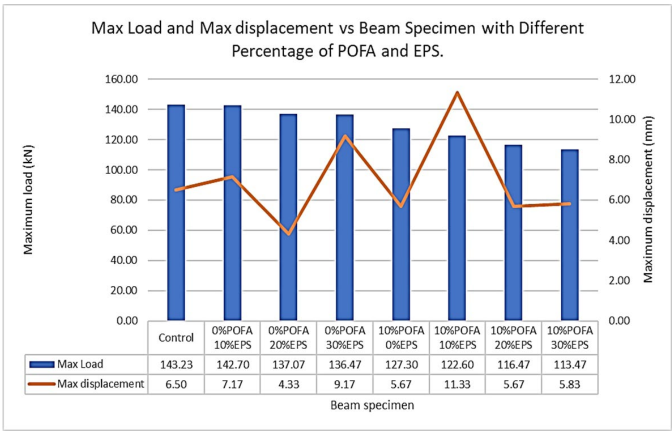

Fig. 6. Maximum load and maximum displacement vs beam specimen

4.3. Crack pattern

Based on Figs. 7 and 8, the crack pattern on the reinforcement beams showed a significant vertical flexural crack. Vertical flexural cracks were mainly characterized as perpendicular cracks to the beam's longitudinal axis [14]. The crack on the beams can be concluded as a flexural crack. Usually, flexural cracks are caused by the maximum load placed in the middle of the beam. Furthermore, insufficient flexural strength of a beam is indicated by flexural cracks appearing when bending begins. In addition, the crack pattern for Figs. 7-8 is flexural cracks with some shear cracks occurred to the beam. A crack with close to

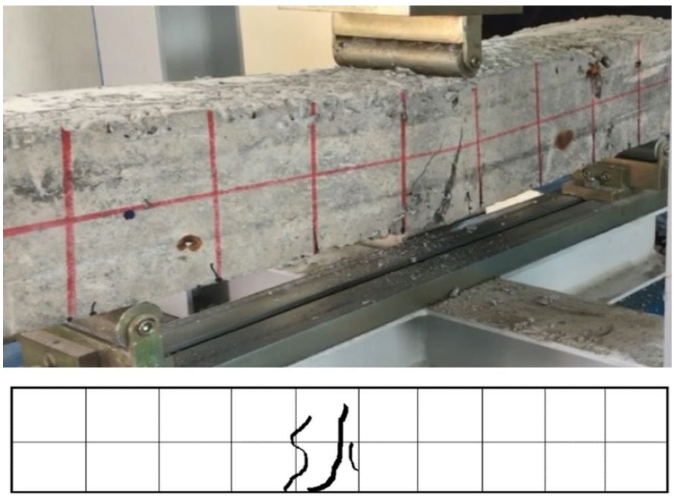

Fig. 7. Normal reinforced concrete beam's crack pattern

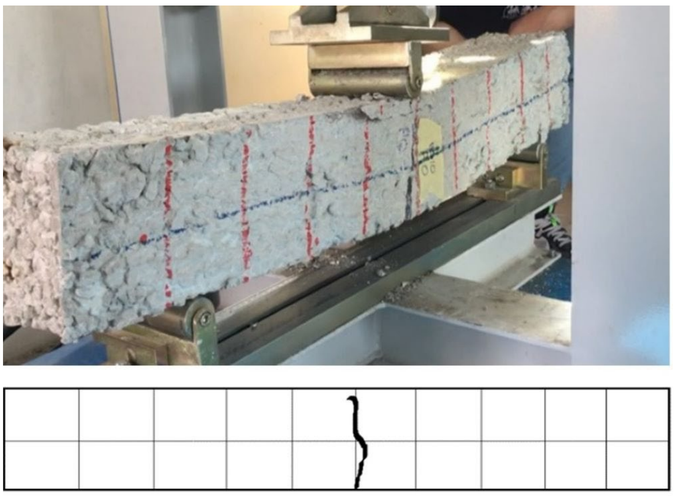

Fig. 8. Reinforced concrete beam's crack pattern with 10% EPS

45 degrees angle can be said as a shear crack . Shear cracks were developed when the acting shear on the section exceeds the resisting shear capacity in certain situations. This happens due to an inadequate reinforced beam structure. Because of the simultaneous bending and shearing action, these sorts of cracks are properly described as diagonal tension cracks. Furthermore, the reinforced concrete beam's crack pattern for Figs. 11-14 shows generally flexural crack with some inclined flexural-shear crack. The loss of flexural strength and flexural deflection capacity tends to decline with increasing POFA; this might be explained by a reduction in crack width [15]. The deflection increased of RC beam due to increased EPS replacement levels and the failure

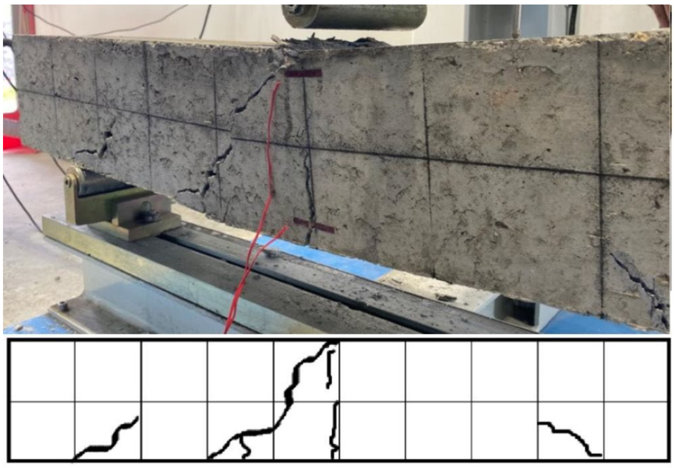

Fig. 9. Reinforced concrete beam's crack pattern with 20% EPS

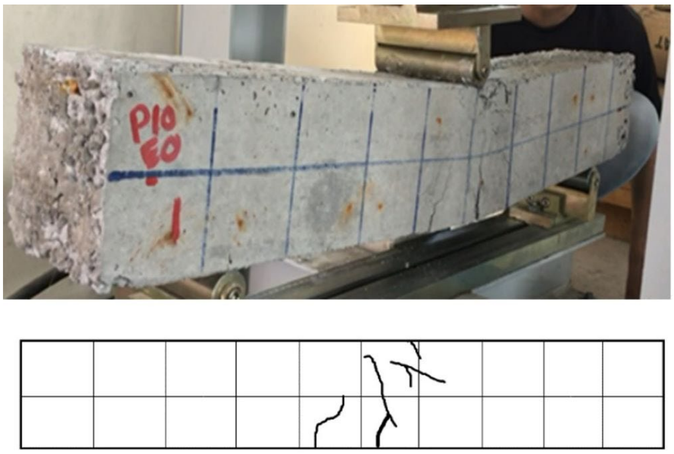

Fig. 11. Reinforced concrete beam's crack pattern with 10% POFA

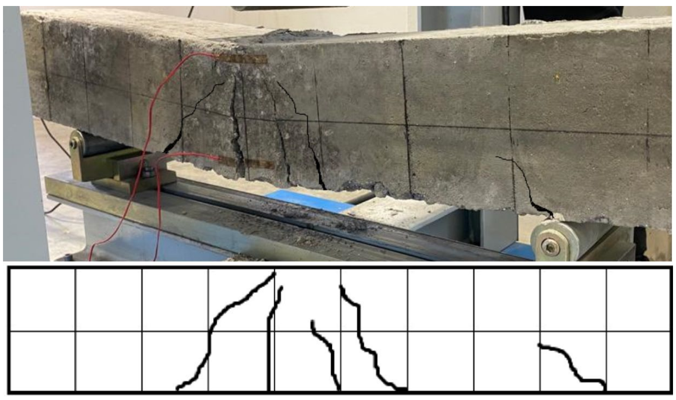

Fig. 13. Reinforced concrete beam's crack pattern with 10% POFA and 20% EPS

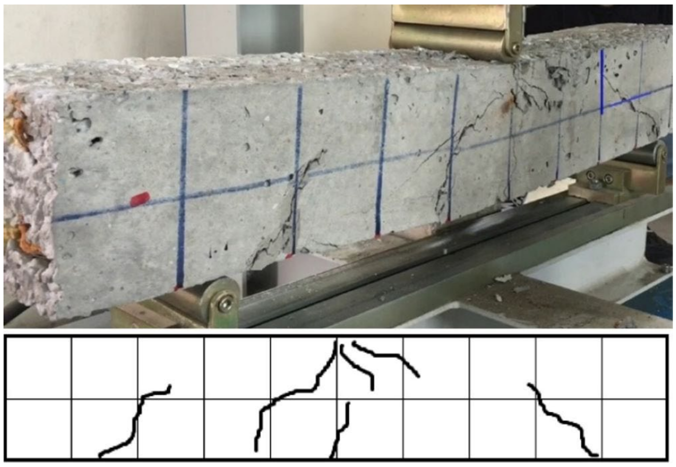

Fig. 10. Reinforced concrete beam's crack pattern with 30% EPS

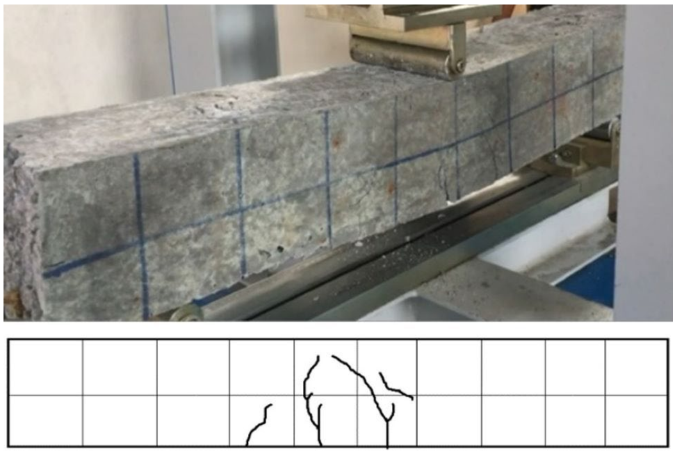

Fig. 12. Reinforced concrete beam's crack pattern with 10% POFA and 10% EPS

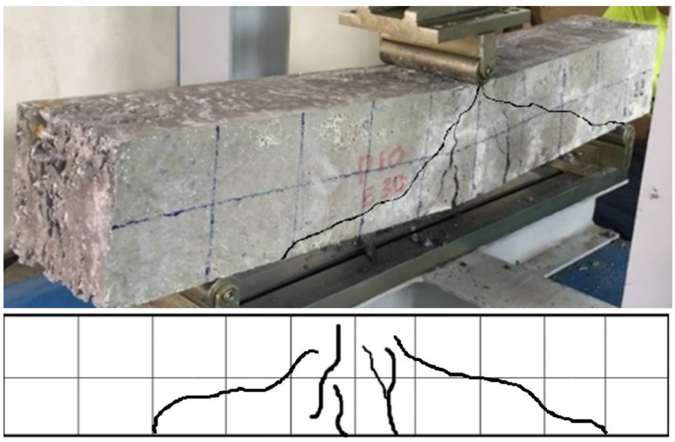

Fig. 14. Reinforced concrete beam's crack pattern with 10% POFA and 30% EPS

mode was primarily shear. As the percentage of EPS and POFA increases above 20% for all specimens, cracking starts to change to shear cracking. The length of crack spread under loading was also decreased with an increase in EPS percent [4].

5. Conclusions

The conclusion can be made that the concrete with 10% POFA without EPS shows a compressive strength slight increase which is 0.26% higher than normal concrete. Utilizing greater EPS and POFA in the concrete will reduce the compressive strength and capacity of reinforced concrete beams. A decrease in load-carrying capability and flexural performance of EPS and POFA reinforced concrete beams was observed when compared to normal reinforced concrete beams. 10% POFA and 30% EPS showed the lowest maximum loading than others but still higher value compared to the design load of 30 kN. Additionally, the POFA and EPS-reinforced concrete beam's crack pattern may be categorised as flexural cracking, and some of the cracks tend to be shear cracks with angles that are close to 45 degrees. As the percentage of EPS and POFA increases above 20% for all specimens, cracking starts to change to shear cracking. The mechanical characteristics of concrete are directly influenced by factors such as cement content, POFA volume, and EPS content.

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