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FLEXURAL CHARACTERISTICS OF REINFORCED CONCRETE BEAMS CONTAINING LIGHTWEIGHT AGGREGATE IN THE TENSILE ZONE

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ABSTRACT

In reinforced concrete design, the concrete in the tensile zone is assumed to be ineffective and increase the dead load of the structure. In order to reduce the self-weight of reinforced concrete beam, this paper examines the flexural performance of reinforced concrete beams containing lightweight and normal weight concrete. The lightweight concrete was made from waste polystyrene. Four reinforced concrete beams were prepared with different depth of lightweight concrete. The control beam B1 consists of normal concrete. In Beams B2, B3 and B4, the depth of lightweight concrete was 25%, 50% and 75% of the total depth of the beam measured from the bottom surface respectively. The beams were subjected to four-point bending test and was loaded in increments until failure. At each load increment, the central deflection was determined. The propagation of cracks and the mode of failure were monitored. As the depth of lightweight concrete increases, the failure load decreased. The presence of lightweight aggregate tends to cause a brittle failure. In addition, the mode of failure for reinforced concrete beams containing lightweight concrete was shear failure.

Keywords: cracks, lightweight, load defelection, structural performance, waste

1. INTRODUCTION

Nowadays, the use of lightweight is increasing, not only for structural applications, but also for other purposes, such as pavement filling. To us it is very crucial in Lebanon to perform such improvement that made us study and make experiments. Using polystyrene in construction helps in one way to reduce pollution problem and in other way can help in saving materials and money for construction.

Sabaa [1] reported that the polystyrene aggregate concrete with the density between 1750 and 1850 kg/m3 showed no reduction in its dynamic modulus of elasticity when it was subjected to 450 cycles of freezing and thawing. Hence, these studies indicate that polystyrene aggregate concrete is more durable under severe exposure conditions than the normal weight concrete. The polystyrene aggregate particles act as energy absorbing component in the concrete system, thus negating the disruptive expansive stresses created by the changes in the exposure conditions or by the chemical attack.

Minapu et al [2] have presented experimental investigation consisting of casting and testing of 9 sets of cubes, cylinders and prisms consisting of different proportion of pumice stone used as a replacement to natural coarse aggregate. Each set consisted 4 cubes, 2 cylinders and 2 prisms for determining compressive strength, tensile strength and flexural strength respectively. Pumice stone was used as a partial replacement to natural coarse aggregates in different proportions along with fly ash and silica fumes in varying proportions. Cubes, cylinders and prisms were casted adopting M30 design mix proportions and then cured for 28 days. After 28 days they were tested for compressive strength, tensile strength and flexural strength. From the results it was concluded that light weight aggregate is in no way inferior to natural coarse aggregates and they can be used for construction.
Desai et al [3] have attempted replacing natural coarse aggregates with lightweight cinder aggregates. Cinder in proportions varying from 0% to 100% was used as coarse aggregate forM20 design mix. Various cubes and cylinders were casted and tested for compressive strength, tensile strength, shear strength at the end of 28 days of curing. It was concluded that even after replacing natural aggregates by 75% the compressive strength was greater than the target strength. Thus cinder can be used as a replacement for natural coarse aggregates.
Parhizkar et al [4] have presented experimental investigation on the properties of volcanic pumice lightweight aggregates concretes. To this end, two groups of lightweight concrete (lightweight coarse with natural fine aggregates concrete, and lightweight coarse and fine aggregates concrete) are built and the physical/mechanical and durability aspects of them are studied. The results of compressive strength, tensile strength and drying shrinkage show that these lightweight concretes meet the requirements of the structural lightweight concrete.

2. SCOPE OF STUDY

The wider aim of this research is to reduce the weight of structural elements in order to construct more efficient structures. This will allow using less materials or more utilization of waste materials, thus contributing to sustainable development. The specific objectives are to determine the structural behaviour of reinforced concrete beams containing a combination of lightweight and normal weight concrete. Waste polystyrene is used as lightweight aggregate in order to reduce the density of concrete. This included the load deflection, crack propagation and mode of failure. The beams had the same size and the only variable was the depth of lightweight concrete. Future investigations will examine the behavior of reinforced concrete beams containing waste polystyrene under impact and dynamic loading [5,6]

3. EXPERIMENTAL WORK

3.1 Mix Design

Two mixes were prepared in order to be used in this research. The first mix is a normal weight concrete mix (NWC) with a mixing ratio of 1 (cement): 2 (fine aggregate): 4 (coarse aggregate) by weight, and the second mix is a light weight concrete mix (LWC) with the same proportion as the NWC mix but with a 100% coarse aggregate replacement by polystyrene. This lightweight material was brought from factories were machines and devices are usually covered by it to protect it from being broken (Figure 1). The free water to cement (W/C) ratio for all concrete mixes was kept constant at 0.6. These proportions of materials were selected based on initial trial mixes to achieve adequate workability. The details for all mixes are presented in Table.1.

Table1. Details of concrete mixes

Quantities per cubic meter:			(Kg/m^3)		
Sample	Cement	Water	Sand	Gravel	Polystyrene
NWC	450	225	743	1543	0.0
LWC	450	225	743	0	14.3

Figure 1. Polystyrene after being processed

3.2 Reinforced Concrete Beam Details

Reinforced concrete beams of dimensions 200mm x 300mm x 1500mm were used. All details are illustrated in figure 2. Four case of casting were considered. The first beam (B1) was fully cast by NWC. The second beam (B2) was cast using LWC until 25% of the total height, and the remaining height was cast using NWC. The third beam (B3) was cast with LWC until half of the height, and the remaining height was cast using NWC. Finally, the fourth beam (B4) was cast by LWC until 75% of the total height, and NWC was used for the remaining part. Figures 3 to 6 show the four beams considered in this study.

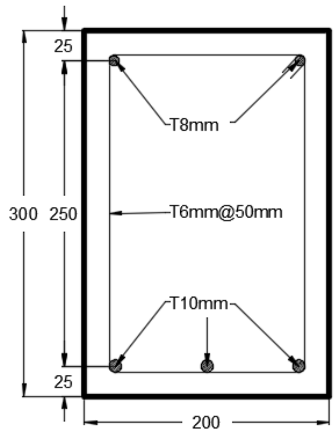

Figure 2. Beams details

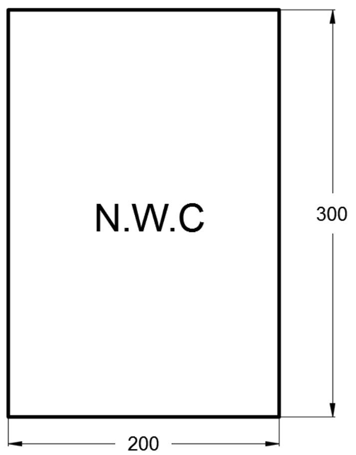

Figure 3. Beam (B1)

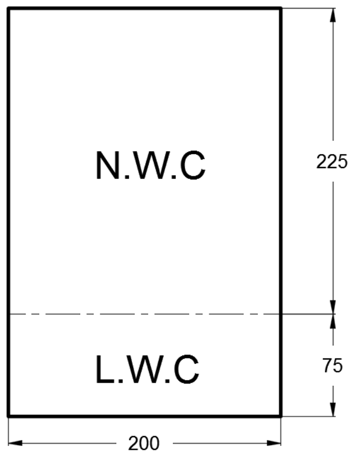

Figure 4. Beam (B2)

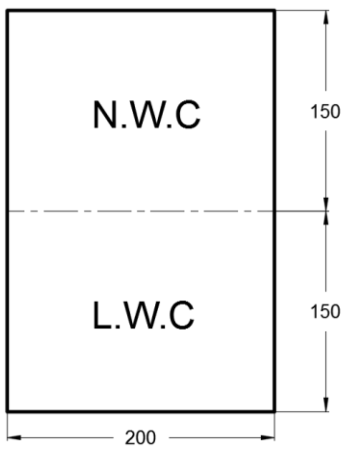

Figure 5. Beam (B3)

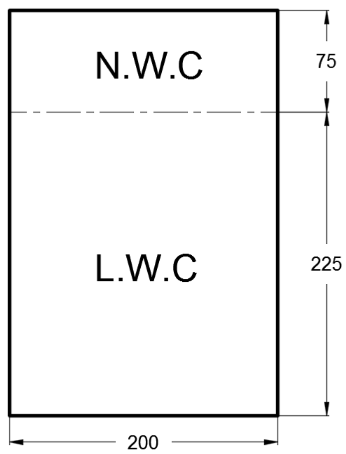

Figure 6. Beam (B4)

3.3 Casting

The initial step was to weight the materials (i.e. cement, normal coarse aggregate, lightweight aggregate, sand and water) required for each mix. Timber moulds were used for cube and beam specimens and steel moulds were used to cast the cylinders. Before casting, the moulds were cleaned and oiled. The cubes were 100mm in size and were used to determine the compressive strength and density. Cylindrical steel moulds of dimensions 100mm diameter and 200mm height were used to determine the Modulus of Elasticity (E). The beams were used to study the flexural performance and had dimensions of 200mm x 300mm x 1200mm. The dry materials were placed in the following sequence: coarse aggregates, fine aggregate and cement. They were mixed dry until for 2 minutes. The water was then added slowly a homogenous mix was achieved as shown in Figure 7. The slump for each mix was determined before casting as shown in Figure 8. The slump for the NWC and LWC was 12 mm and 15 mm respectively.

Figure 7. Mixing of concrete

Figure 8. Control mix slump

The cube specimens were cast in two layers in order achieve good compaction and to remove entrapped air. For each mix, 9 cubes, 3 cylinders and 4 beams were cast. All specimens were covered in their mould for 24 hours when demoulding took place. The cubes and cylinders were placed in a water tank at about 20℃ whereas the beams were covered with plastic sheeting in the laboratory until testing. The temperature of the laboratory varied between 18 and 25℃ during that period.

3.4 Testing

The testing for compressive strength and modulus of elasticity conformed to BS EN 12350-1:2000 [7] and BS EN 12390-13:2013 [8] respectively.

The flexural behaviour was assessed using the four-point test as shown in Figure 9. The beam was loaded in increments of 5kN increment until yielding. At each load the central deflection was determined. Also the load at first crack was monitored. Then, the loading continued until failure. During testing, the initiation and propagation of cracks were noted.

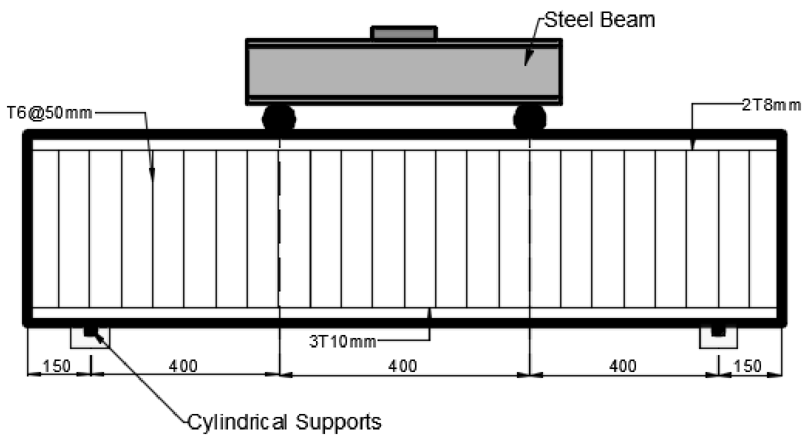

Figure 9. Longitudinal section of beam with supports and loads (dimensions in mm)

4. RESULTS AND DISCUSSION

Figure 10 shows the average density of each concrete sample. The density of NWC was 2416Kg/m^3, whereas LWC, a noticeable reduction in density occurred. The reduction was about 50%.
Figure 11 and 12 show the compressive strength and modulus of elasticity at 1, 7, and 28 days for both concrete mixtures respectively. The compressive strength for NWC is greater than the mix with LWC. The same trend was observed for the modulus of elasticity.

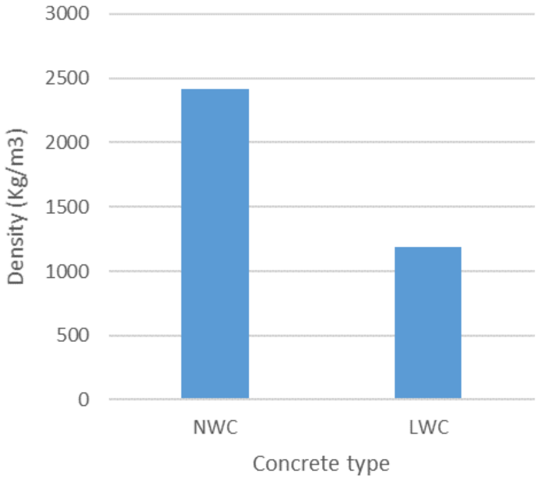

Figure 10: Average Density for concrete samples

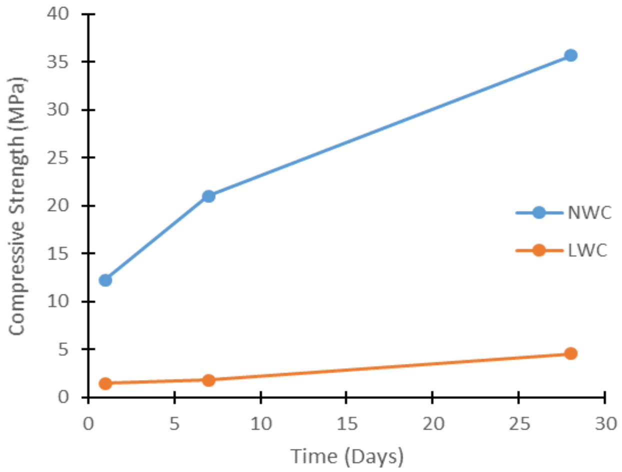

Figure 11: Compressive Strength

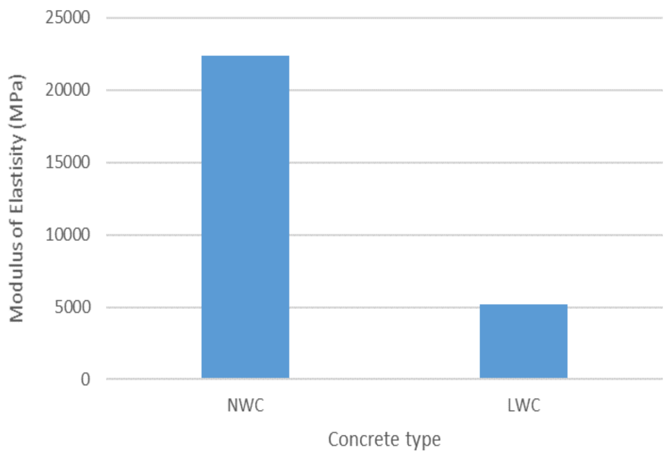

Figure 12: Modulus of Elasticity

Figure13 shows the load deflection curve for all concrete beams. For beam (B1) the deflection increases as load increases approximately linearly to specific load which the elastic region and after this region the rate of deflection increases to reaches failure at 212 KN. Therefore, this beam had a normal flexural failure (Figure 14), which starts with elastic to inelastic to reach rupture. As for beams (B2) to (B4) that contain LWC in the tensile zone, the failure occurred due to shear as can be seen in figures 15 to 17. Therefore, the beam's original flexural strength was not reached.

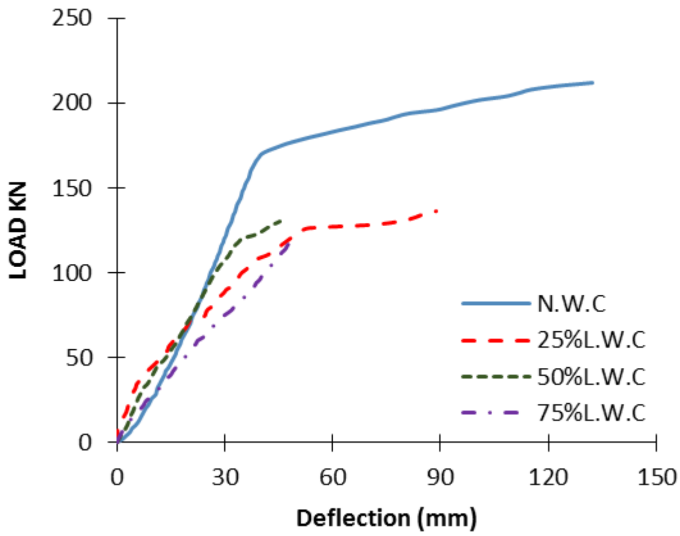

Figure 13. Load deflection curves for all samples

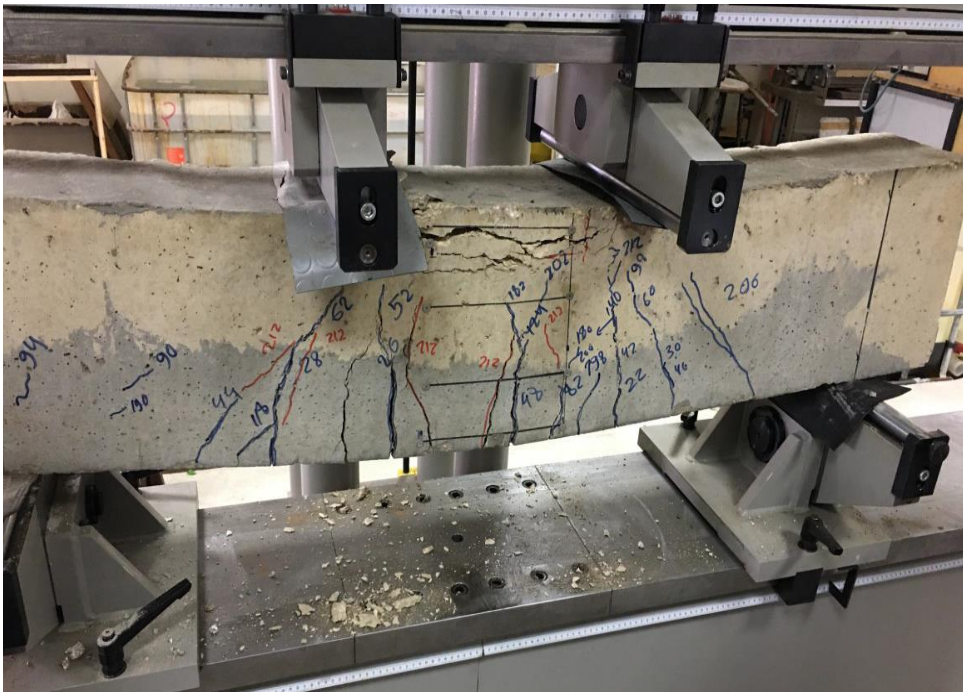

Figure 14. Damage pattern for beam (B1)

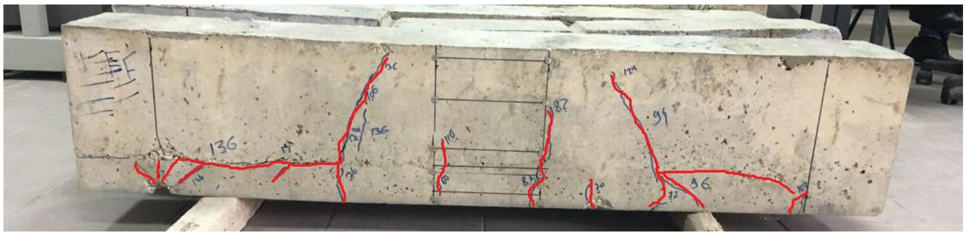

Figure 15. Damage pattern for beam (B2)

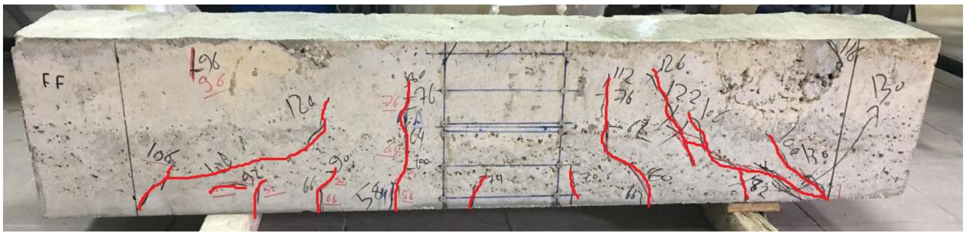

Figure 16. Damage pattern for beam (B3)

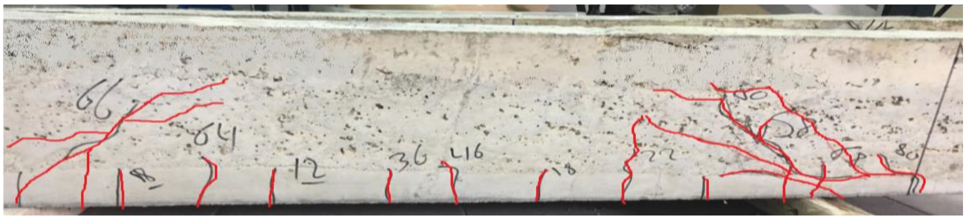

Figure 17. Damage pattern for beam (B4)

5. CONCLUSION

The following conclusions are based on the results of the current investigation:

1- An increase in the depth of lightweight concrete in reinforced concrete beams leads to a decrease in the load at failure.
2- The beams were design to fail in flexure. However, shear failure was dominant in reinforced concrete beams containing lightweight aggregate as indicated in diagonal cracks at failure. This suggests that the shear capacity of lightweight concrete should be enhanced.
3- Reinforced concrete beams containing lightweight aggregate tend to be more brittle compared with those containing normal aggregate.

6. REFERENCE

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