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COMPARING COMPRESSIVE STRENGTHS OF LAYERED AND RANDOM PLACEMENT OF EXPANDED POLYSTYRENE WASTES IN QUARRY DUST BLOCKS

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Abstract — Despite intense research on building materials, the challenge of finding cheap and lightweight construction materials still persist for persons wishing to construct a house. A material that is getting attention of researchers and lightweight is Expanded Polystyrene (EPS). The aim of this study was to compare compressive strength and mass of blocks made when EPS were mixed randomly or in layered manner in cement-quarry dust mortar. The EPS wastes were placed randomly and in a single layer so as to give percentage volume of 0% (control), 10%, 20%, 30%, 40% and 50% EPS of the cube of 150 mm. The results showed that the average compressive strength of mortar was 18.67 ±1.33 N/mm^2. The strength reduction proportionality factor for layered mixing was 0.76 to 1 and 0.29 to 1 for random mixing. This showed that reduction of strength was greater in random mixing than layered mixing. Increase of EPS above 30% randomly, resulted in lightweight blocks of between 1319 and 1669 Kg/m^3, whereas increasing EPS in layered manner above 50% resulted in lightweight blocks of densities less than 1679 Kg/m^3. This research showed that 40% EPS randomly mixing resulted in a light block which met the minimum strength criteria of 3.6 N/mm^2.

***Keywords*:** Compressive strength, density, expanded polystyrene wastes, quarry dust

1.0 INTRODUCTION

Cost of construction materials influence affordable housing. Materials like bricks, blocks and stones are used to construct walls in houses. Using burnt bricks for walling can reduce costs as they are available everywhere, however, bricks are being discouraged as they lead to forests depletion, because firewood is needed to fire kilns during brick making. In fact, bricks require energy of 2.3-9.3 MJ/Kg while in the kiln [1]. Other construction materials used in Kenya include interlocking earth blocks and expanded polystyrene (EPS). Proponents of EPS encourage its use as it results in overall cost reduction by 25 % and construction time by 50%, therefore ideal building material for the poor. Another advantage of EPS is that it results in thermal insulation of houses [2]. On the contrary, EPS use in construction, leaves behind a trail of wastes and hence the need to recycle them in this era of sustainable development. Indeed, Sustainable Development Goal number 12 calls for responsible consumption and production in the world [3]. A country like Japan recycles over 90.4 % of EPS used [4]. In Kenya, no recycling of EPS is done because it is economical to produce EPS than recycle [5] and hence the need for recycling. The wastes can be recycled by incorporating them in making of blocks. As the demand for housing increases so is the use EPS, consequently leading to more generation of EPS wastes.

Expanded polystyrene (EPS) is a non-biodegradable material that contains 98% air and 2% polystyrene and therefore it is light. The density of EPS varies from 10 kg/m^3 and 35 kg/m^3, elastic modulus of 3.1-3.3 GPa, Tensile strength of 30-55MPa and Thermal conductivity of W/mK [6]. It is known to have good thermal, sound and water resistance. Due to its lightness it can be used to make lightweight concrete. Most of the EPS panels are used to make walls and upper floors. The panels are normally reinforced with steel mesh enabling the panels to transmit shear and compression forces safely to the foundation. EPS technology has been used in South America, North America, Europe, Middle East, West Africa and South Africa. It was first introduced in Kenya and by extension East Africa in 2013. National Housing Corporation, a parastatal in Kenya, built a factory to manufacture EPS in Kenya [7].

The minimum requirements for construction materials are stipulated in the American Society for Testing and Materials (ASTM). Such minimum requirements include compressive strength for building blocks and mortar. The mortar type M can withstand high compressive forces as well as lateral loads (ASTM C270)[8] and this is good for the EPS panels. Bricks have a minimum compressive strength of 5 N/mm^2 while concrete blocks have a minimum strength of 3.6 N/mm^2 [9]. According to ASTM standards, concrete blocks are lightweight if the density is less than 1680 Kg/m^3 and heavyweight if the density is more than 2000 Kg/m^3. Another study talks of lightweight concrete as having a density of less than 1800 kg/m^3 [10].

Currently, a lot experimental research work on global level is being done on EPS. For example, [11] investigated use of EPS wastes and fly ash. The researchers varied ratio of EPS from 0, 60 and 100%. Their results showed that increasing EPS had an effect of reducing the compressive strength of concrete. The research used 1 part of cement to 6 parts of aggregate which is the same as the one used in this study. Mixing of EPS with mortar was done randomly in a planetary mixer. To avoid segregation, the EPS beads were stabilized with clay which can be scarce in some parts of Kenya where clay cannot be easily obtained.

Another study by [10], considered random mixing by replacing aggregates both fine and coarse aggregates with EPS beads. The use of fine and coarse aggregate can be a challenge in areas where the fine aggregate is far and hence increasing the construction cost because of the transportation cost.[12] considered using EPS beads reinforced with polyamide-66 in coming up with lightweight concrete. A study by [2] compared densities of concrete made of recycled EPS and recycled concrete. As [7] and manufacturers worldwide advocate and promote the use of EPS, there is need for in-depth study on EPS so as to give more information that will guide decision makers at the county and national levels in Kenya. From above studies, it is evident that most researchers have concentrated on EPS, however, none of them has done comparison of layered and random mixing of EPS in concrete. The objective of this study was to compare random mixing and layered mixing of quarry dust and cement mortar with increasing quantities of EPS by volume.

2.0 METHODOLOGY

2.1 MATERIALS

Mortar of cement and quarry dust was used in this study. The cement from Bamburi cement company branded Bamburi Tembo CEM IV/B[P]32.5N pozzolanic cement to KS EAS18-1:2001[13]. Quarry dust of fineness modulus of 4.4 from Kuinet Quarry in Eldoret town was used after conducting sieve analysis as per BS 812: Part 103.1:1985 [14]. The quarry dust rock was of volcanic origin. Expanded Polystyrene wastes were sourced from National Housing Corporation factory, Mlolongo in Machakos County, Kenya.

2.2 MIXING OF MATERIALS

The ratio of cement to aggregate was maintained at 1: 6 with water cement ratio of 0.55. EPS beads were broken into smaller pieces of around 3 mm close to the size of beads. Expanded Polystyrene wastes incorporation into the mortar was done in two ways and each had five treatments. The first was layered and the second was random mixing. The control experiment was a sample with 0% EPS wastes.

Layered mixing was done by sandwiching the EPS wastes in the mortar so as to achieve 10%, 20%, 30%, 40% and 50% EPS composition by volume in a cube of 150 mm by 150 mm by 150 mm. The layered placement was done so as to ensure that the minimum thickness of mortar was not less than 25 mm as required by ASTM C90-11[15]. For this experiment the minimum was 37.5 mm on either side representing 50% EPS.

2.2.1 PROCEDURE FOR RANDOM MIXING

The following five steps were used in carrying out random mixing: First, 60 Kg of quarry dust and 10 Kg of cement were weighed and dry mixed in a concrete mixer. Secondly, EPS used was measured as per the percentage volume in the treatment and pre-wetted to create a bond between the EPS particles. For example, if 10% waste was required, EPS beads were placed in the mould to a depth of 15mm. This was repeated for all the other treatments. The third step was measuring the cement quarry dust mixture as per the percentage volume. For example, if 10% wastes were required, the depth of the cement-quarry dust mixture was 135 mm. Fourth step entailed mixing of cement, quarry dust, EPS wastes as per percentage volume in the mould until all the EPS beads were completely and randomly distributed in the mixture as per BS EN 12390-2:2009[16]. The last step was removing the cubes from the moulds and curing in water for 28 days before measurement of compressive strength and mass as per BS EN 12390-3:2009[17].

2.2.2 PROCEDURE FOR LAYERED MIXING

The following five steps were used in carrying out layered mixing (Figure 1): First and foremost, 60 Kg of quarry dust and 10 Kg of cement were weighed and dry mixed in a concrete mixer. Secondly, EPS to be used was measured as per the percentage volume in the treatment and pre-wetted to create a bond between the EPS particles. For example, if 10% waste was required, EPS beads were placed in the mould to a depth of 15mm. This was repeated for all the other treatments. Thirdly, the cement-quarry dust mortar was poured into moulds to depths as per the treatment. For instance, 10 % EPS, 67.5 mm of mortar were placed first to be followed by EPS (15 mm) then 67.5 mm of mortar. This procedure was repeated for all the other treatments. The fourth step was removal of the cubes from the mould and keeping in water for 28 days before measurement of compressive strength and mass as per BS EN 12390-3:2009[17]. The last step was application of compressive force parallel to the EPS layers for cured cubes.

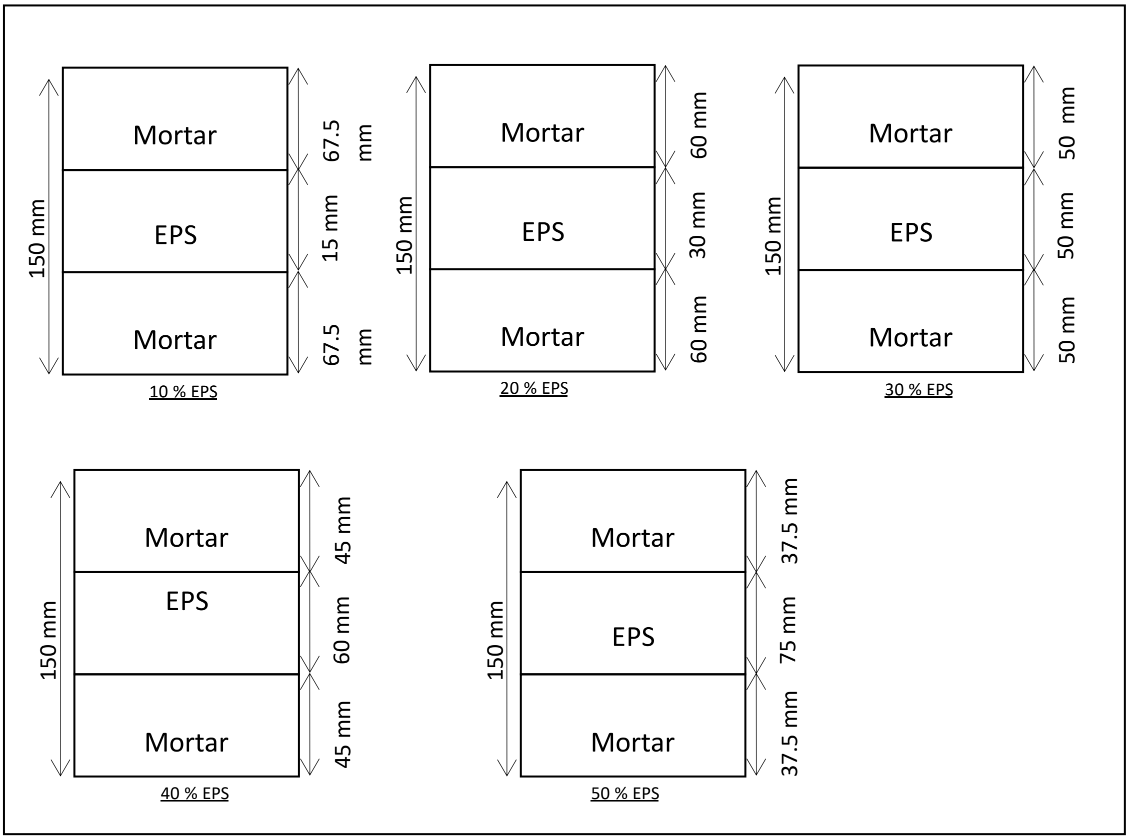

Figure 1. Layered mixing of EPS wastes

For random mixing, the EPS beads were mixed randomly with the mortar. The EPS wastes were also 10%, 20%, 30%, 40% and 50% composition by volume. Each sample was replicated thrice. Both layered and randomly mixed blocks as shown in Figure 2 were put in the cube molds and cured for twenty-eight days for the determination of compressive strength and mass at 28 days after casting. The average mass and compressive strength plus or minus standard deviation was recorded. Compressive strength was done according to BS 1881 part 111:1983 [18] using motorized compression/tension machines. The loading was applied at low loading rate.

(a) (b)

Figure 2: (a) Randomly mixed cube (b) and layered mixed cube

Compressive strengths response (K_s) to percentage of EPS panels was represented by the following equation.

$$1 - \frac{S}{S_x} = K_s \left[1 - \frac{EPS}{100} \right] \quad (1)$$

Where S_x is the maximum strength (Control strength), S is the difference between the control strength and the strength of the treatment in N/mm^2, EPS as Percent EPS of the treatment and K_s is the proportionality factor between the reduction of strength in relation to increase of EPS percentage.

The proportionality factor K_s for layered was divided by K_s for random to get a ratio for comparison.

3.0 RESULTS AND DISCUSSIONS

The compressive strength and mass of layered and random mixing are shown in Table 1.

Table 1. Average mass and compressive strengths for layered and random mixing

% EPS	Average mass (Kg)		Average compressive strength(N/mm^2)	
	Random	Layered	Random	Layered
0	7.32 ±0.24	7.32 ±0.24	18.67 ±1.33	18.67 ±1.33
10	6.43 ±0.19	6.65 ±0.30	10.00 ±0.67	15.41 ±1.20
20	6.27 ±0.06	6.33 ±0.24	9.04 ±0.46	13.56 ±1.02
30	5.63 ±0.10	5.92 ±0.35	5.19 ±0.34	12.44 ±1.33
40	5.07 ±0.16	5.78 ±0.03	3.85 ±0.34	9.56 ±1.14
50	4.45 ±0.35	5.67 ±0.03	2.74 ±0.57	7.19 ±0.34

In Table 1, it can be seen that the masses of layered cubes were more than the masses of randomly mixed ones. This was attributed to the dense packing of ingredients in layered cubes than randomly mixed cubes. Random mixing was thought to have some voids and hence the less mass. The control experiment resulted in the highest mass of 7.32 kg while the least was 4.45 kg observed in 50% EPS. The density of 2169 kg/m^3 for the control was close to 2060 Kg/m^3 specified by Code of Practice for Dead and Imposed loads 2011[19]. Furthermore the block could be regarded as heavyweight is its density was more than 2000

Kg/m^3. The lightest block had a density of 1319 kg/m^3. Lightweight blocks were observed for 30%, 40% and 50 % EPS for random mixing and only 50% EPS for layered mixing. This agrees with [2] who found lightweight concrete when EPS was 30%. The critical mass for transitioning to lightweight block was 5.67 Kg.

The highest percentage reduction in mass between the control and 50% EPS randomly mixed block was 39%. Percentage reduction in mass was more for random mixing than layered mixing.

Table 1 reveals that the compressive strengths for layered were more compared to those of randomly mixed. This shows that compressive strength was directly proportional to mass. The compressive strength of the control sample had 18.67 N/mm^2. This strength met the minimum requirements for mortar type M which should have a minimum strength of 17.2 N/mm^2 as per ASTM C270 [8]. All the layered cubes had compressive strength in excess of 3.6 N/mm^2 normally used for making concrete blocks. On the other hand, for random mixing all of them met the requirement except the 50% EPS substitution which had strength less than 3.6 N/mm^2. It can be inferred from Table 1, that 40% EPS substitution randomly was the one that had the least density and met the strength requirement. This value is higher than 30% observed by [20]. The difference could be attributed fine aggregate used. This study used quarry dust unlike [20] who used river sand.

Comparing the percentage reduction in strength, it was observed that the highest reduction of 85% was observed in the cubes made by incorporating 50% of EPS in the mortar randomly (Figure 3). If 50% EPS was incorporated in layered manner it resulted in reduction of compressive strength of about 61.5% as shown in Figure 3.

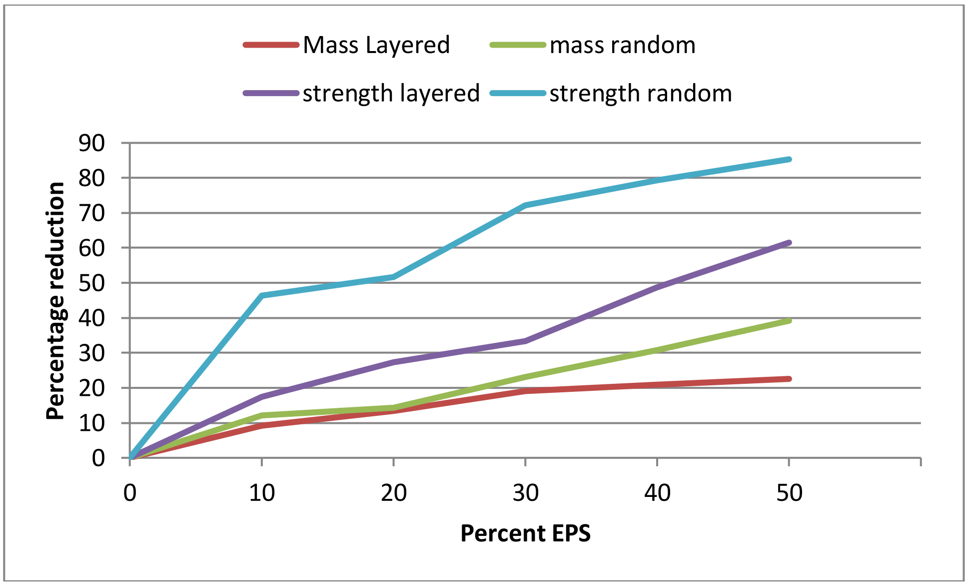

Figure 3. Graph of percent reduction in strength against percentage of EPS wastes

Comparing strength and mass, it was seen that compressive strength was more sensitive to EPS increase than mass (Figure 2). This means that increasing EPS wastes in making blocks severely impacted more on compressive strength than the mass. Therefore, in cases where lightweight blocks are required, random mixing may be preferred. Where blocks of high compressive strength are required such as load bearing walls, layered blocks where EPS wastes are sandwiched between the mortar may be used. The Ks values for layered was more than random mixing as shown in Table 2. Increasing EPS by 10 – 20%, meant that random layered strength was reduced by one and half times of the layered. Interestingly, reduction in strength in random was 2.5 times higher than layered ones for EPS ratios of between 30 and 50 percent as shown in Table 2.

Table 2. Proportionality factors for layered and random mixing

Percent of EPS	Ks layered	Ks random	Ratio between Ks layered/Ks random
0	1.00	1.00	1.00
10	0.92	0.60	1.54
20	0.91	0.61	1.50
30	0.95	0.40	2.40
40	0.85	0.34	2.48
50	0.76	0.29	2.62

4.0 CONCLUSION

From the findings it was evident that compressive strengths and masses were reducing as the percentage of EPS increased from 0 to 50%. More reduction of mass and compressive strength was observed in random mixing than layered mixing. Layered mixing resulted in higher strengths than random mixing. In addition, 40% EPS random mixing brought about the lightest block that met the minimum strength requirement. This research did not compare the results with the hollow cubes; hence future research is needed to compare how strength of hollow blocks behaves when compared with those of EPS.

5.0 ACKNOWLEDGEMENT

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