Pre-Loading Impact on Mechanical Properties of Sand-Polystyrene-Cement Mix

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ABSTRACT:
A laboratory study on the formation of lightweight material by blending sand with polystyrene (EPS) and cement is presented. The effects of pre-loading compositions of EPS-sand, cement-sand and water-sand ratios on strength and densities of lightweight geomaterial were investigated. Mixes of 40%EPS-60%sand (as fine aggregate) and 50%EPS-50%sand with 15%cement to both mixes made up the specimens composition. The density of the control specimen was 1681.3kg/m^3 which was reduced to 1185.8kg/m^3 and 1070.23kg/m^3 when 40% and 50%EPS were added respectively. Hence it was observed that the mixture of 40%EPS and 60%sand with 15% cement content under a pre-loading stress of 600kPa had the highest unconfined compressive strength (UCS) and density. The volumetric mix design used in this study can be applied when robust or lightweight carrying geomaterial is required in construction.

KEYWORDS: *Unconfined compressive strength, Lightweight, Polystyrene, Pre-loading*

I. INTRODUCTION

Recently lightweight geomaterial particularly the expanded polystyrene (EPS) block geofoams have been more widely used in infrastructure rehabilitation and construction of roads and embankments (Frydenlund, 2001). Studies on the properties of EPS materials have been looked into by Chun et. al., (2004). The benefits of ESP geo-blocks were also discussed by Stark et. al., (2004). Nonetheless there are disadvantages in the applications of ESP (Deng, 2001) which include;

[1] Prefabrication of EPS blocks off-site and which involves cost of transportation.
[2] Stiffness and properties of ESP blocks cannot be changed easily to suit in-situ soil properties.
[3] EPS blocks are made into irregular shaped blocks and cannot readily fill irregular volumes.
[4] EPS materials have poor fire tolerance i.e. its level of fire resistance is very low.

However when the use of EPS blocks becomes difficult, lightweight materials made with EPS-sand and cement becomes an alternative Yoonz et. al., 92004). The strength of the EPS beads increases due to cement hydration effect and water is used in enhancing the workability of the mix and to activate hydration in the presence of cement. The densities and properties of the cement-polystyrene-sand (CPS) can be changed easily by adjusting the EPS-sand or cement-sand ratios which also change the densities when pre-loading stresses are applied to the specimens after 12hours before the specimens completely set. The lightweight geomaterial have a low density and yet adequate strength. The main advantage of (CPS) mix lightweight geomaterial is that it can be produced in slurry form and poured to any formwork to set. Hence, it is particularly suitable for use as a load carrying lightweight geomaterial.Although, there is still insufficient information on the application from any standard or code as such, this study is based on laboratory experimentations. The different compositions of EPS-sand, cement-sand, water-sand and the pre-loading effects on density, UCS and Young modulus, E, of the CPS specimens were investigated.

II. EXPERIMENTAL DETAILS

2.1. Materials

Four material constituents were used in the study; cement, EPS, sand and water. The EPS beads were round in shape with diameters ranging between 1.5-2mm which was compressible and almost weightless. Fine aggregate commonly called river sand was collected from a local river in Pretoria, South Africa. Physical constituent properties of the sand are shown in Table 1. Ordinary Portland cement was used as binder and tap water was used for the mixing and curing sessions.

2.2. Mix ratio and material preparation

The mixing ratio in this study is defined as a ratio of two different components batched by percentage volume, i.e. water-soil (w/s), cement-sand (c/s) and EPS-sand (eps/s). The mixing ratios studied herein are given in Table 2. These ratios were selected based on trial mixes of different ratios.

Table 1: Physical constituent properties of sand

Parameters	Results
Water content, w (%)	0.6
Dry Density γ(kg/m^3)	1681.304
Specific Gravity (Gs)	1.6
Particles Size	0.2 - 0.4

The mechanical performances of the lightweight geomaterial were observed to vary. The effect of different mix ratios on the strength as well as pre-loading stresses on the densities and UCS of the lightweight product were recorded. Nevertheless it is noted that the trail mix design was tracked by volumetric batching since EPS were almost weightless.

Table 2: Component ratios of EPS by mass volume to sand

EPS/S (%)	Ratio Water/Cement	Cement (%)	Ratio Cement/Sand	Density γ (kg/m^3)	Total volume (m^3)
10-90	0.4	15	0.17	1541	3.289 x 10^{-4}
20-80	0.4	15	0.19	1359	3.289 x 10-4
30-70	0.4	15	0.22	1264.82	3.289 x 10^{-4}
40-60	0.4	15	0.25	1185.80	3.289 x 10^{-4}
50-50	0.4	15	0.3	1070.23	3.289 x 10^{-4}
60-40	0.4	15	0.38	933.40	3.289 x 10^{-4}
70-30	0.4	15	0.5	796.59	3.289 x 10^{-4}

2.3 Test Method

Measurement by volume of the specimen cylinder with 40-60% and 50-50% of EPS-sand mix was taken based on the targeted density of the lightweight product. 60% sand by volume of the cylinder was measured out and filled to the brim with the corresponding volume of EPS after which water was added according to the mix design. This was homogenous mixed into slurry for 5mins and 15% cement was added. The slurry production took approximately 15mins. After a thorough mix the slurry was cast for the different percentage variations as shown in Figures 1 and the pre-loading stresses were applied after the specimens were allowed to set for 12hours as seen in the pre-loading setup in Figure 2.

Fig. 1: Different percentage EPS-sand variations cured for 7days

The stress variations used were 100kPa, 200kPa, 400kPa and 600kPa and the specimens had dimensions of 129mm height and 56.98mm diameter. After 24hrs the specimens were demolded and cured for 7days and the curing method adopted was done by full immersion of the specimens in water under temperature of about 18-22^{0}C. The specimens were removed from the curing bath after 7days and oven-dried for 1hr under a temperature of 30^{0}C. The height and mass of each specimen was gotten and the respective densities were calculated. The results of the UCS, strains, densities, modulus of elasticity (calculated from equation (1)) and pre-loading stresses for the 40-60% and 50-50% variations are given in Tables 3 and 4 respectively.

Fig. 2: Setup showing pre-loading stress applied after 12hours

Table 3: 40-60% mix with 15% cement content

Density (kg/m^3)	Stress (kPa)	Strain, E (%)	UCS (kPa) at 7days	Elastic modulus (MPa)
1292.5	0.00	188x10^{-6}	142	753
1403.4	200	193x10^{-6}	190	985
1412.3	400	201x10^{-6}	210	1044
1422.5	600	205x10^{-6}	224	1091

$$E_{ct} = 0.043\left[\rho^3 (f'_{ct})\right]^{1/2} \qquad (1)$$

Table 4: 50-50% mix with 15%cement content

Density (kg/m^3)	Stresses (kPa)	Strain, E (%)	UCS (kPa) at 7days	Elastic modulus (MPa)
1240.5	0.00	184x10^{-6}	120	651
1374.3	200	187x10^{-6}	168	898
1387.95	400	194x10^{-6}	186.2	959.5
1401.7	600	201x10^{-6}	206	1024

III. RESULT AND DISCUSSION

3.1 Effects of EPS-sand variations on Density

The results of densities for the tested specimens prepared using different ratios of both EPS and sand are presented in Figure 3. It was observed that by mixing 40%EPS-60%sand the density of the specimen was reduced to 1185.8kg/m^3 which is a significant improvement as compared to the density of the control sample of 1628 kg/m^3. Density change with the ratio of EPS-sand added caused a 1.4kg/m^3 decrease as compared to the control density.

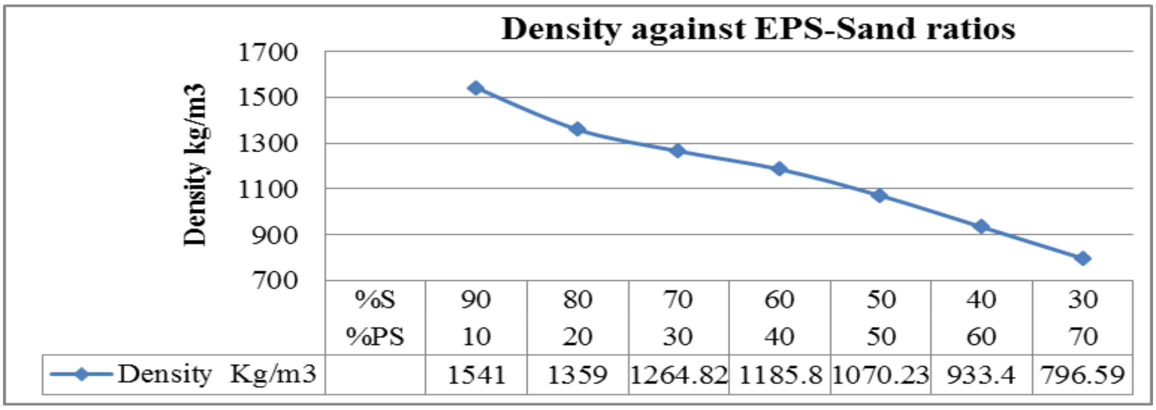


Fig. 3: EPS-sand ratio effect on density of specimens

However, the effect of cement/sand ratio contributed to reasonable increments in the densities of the mix and a significant increase in densities were observed for pre-loaded specimens. The addition of 15% cement was observed to increase the density by 1.2kg/m^3 thereby recording a reduction in the density of the control specimen as the EPS percentage increased as shown in Figure 4. A slight increase in the density with a constant 15%cement content was observed with the addition of water and at a constant W/C = 0.4.

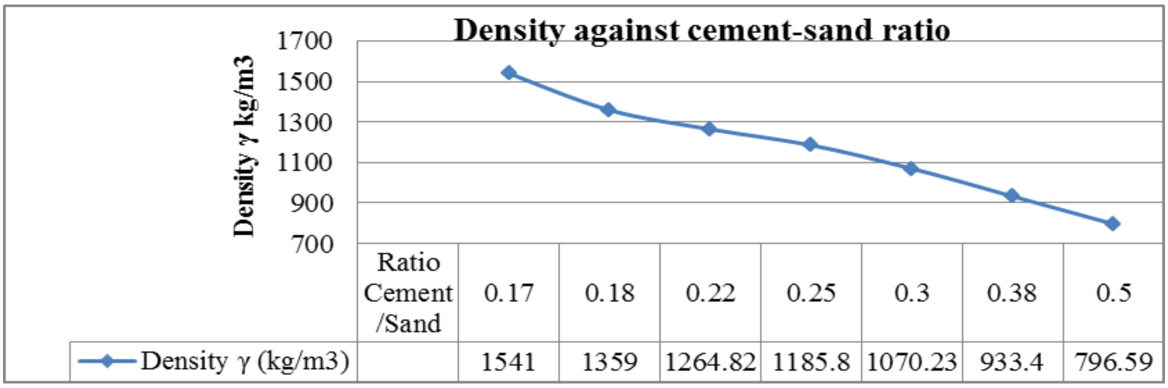


Fig. 4: Cement-sand ratio effect on density of specimens

3.2 Effects of EPS-sand variations on UCS

The EPS-sand ratios were found to have significant effects on the UCS of the respective specimens such that, the percentage variations showed increase in UCS as the densities of the specimens increased. However, over the 7days curing periods the UCS values for the 40-60% mix ratios were observed to be higher than the 50-50% mixes as shown in Figure 5.

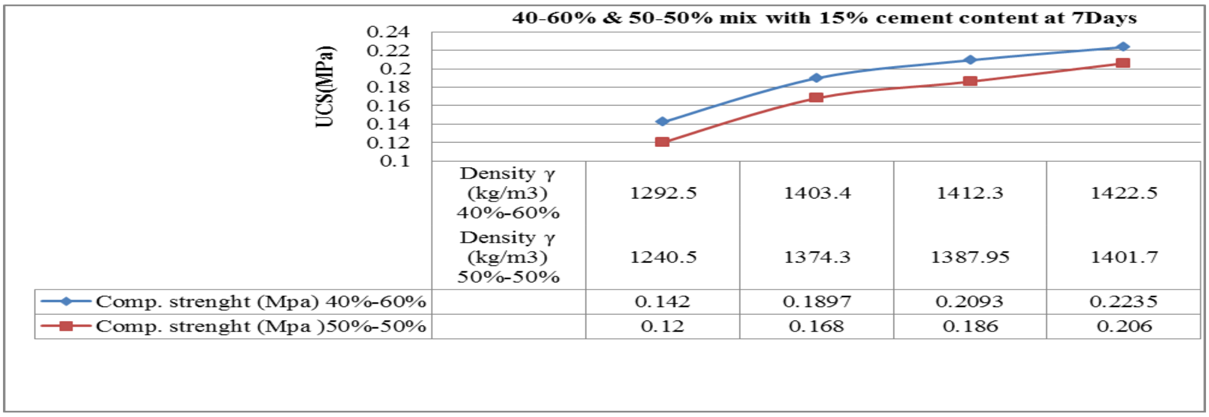


Fig. 5: EPS-sand ratios effect on UCS of specimens

Therefore, this forms the bench mark to which EPS can be blended with sand for 15%cement content in a lightweight geomaterial to serve as a low cost construction material for use in rural development projects over a 7days curing period. The 40-60% percentage ratio mixes had a UCS of 0.2235MPa as compared to the 50-50% percentage variation which was found to be 0.206MPa. The Figure 6 shows the EPS-sand specimens before and after failure occurred when crushed using the compressive strength device.

(a) (b)

Fig. 6: (a) EPS-sand specimen underload (b) EPS-sand specimen failed from loading

3.3 Effects of UCS on elastic modulus

Figure 7 shows the relationship between elastic modulus and the UCS results for the 40-60% mix ratio. It can be clearly seen that as the UCS increases with increasing modulus of elasticity. The increase in elastic modulus can be due to the cementitious binding effect and the density of the specimens from compaction efforts.

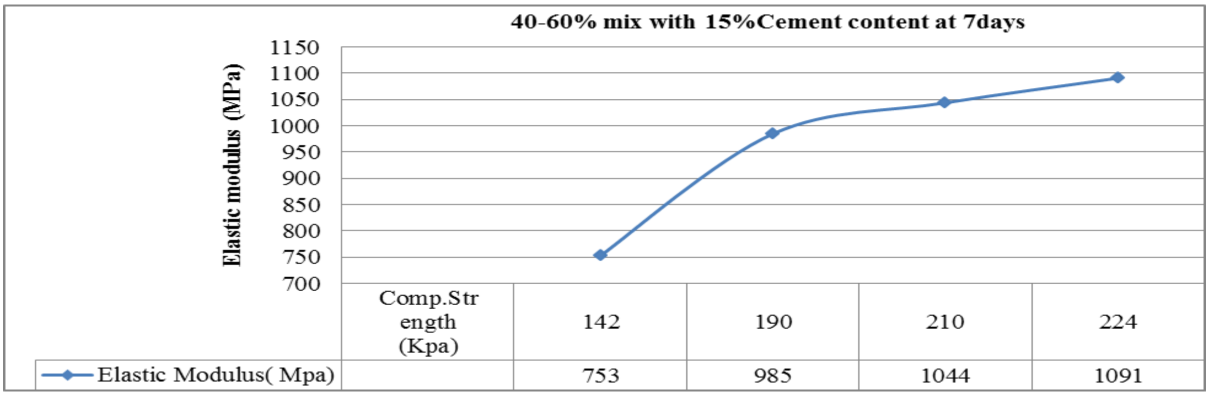


Fig. 7: UCS effects on elastic modulus

This behavior is also reflected in the 50-50% mix ratio over the 7days curing age. Nevertheless, the peak modulus of elasticity for the 40-60% mix was found to be higher than the 50-50% mix ratios. A similar trend was experienced with respect to the UCS and densities of the two different mix ratios in this study.

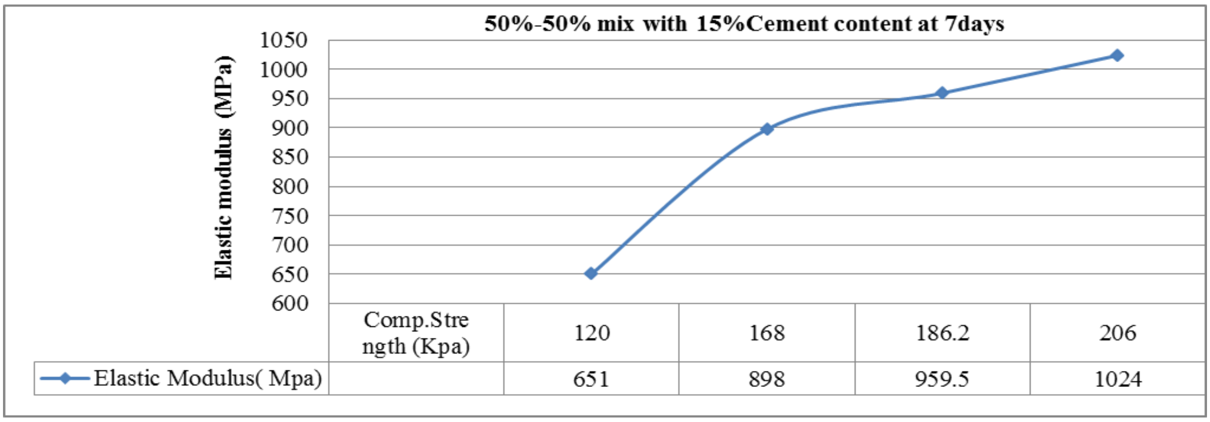


Fig. 8: UCS effects on elastic modulus

A peak modulus of elasticity value for the 40-60% mix was gotten as 1091MPa as against 1024MPa for the 50-50% mix ratio. The relationship between elastic modulus and the UCS results for the 50-50% ratios in shown in Figure 8.

3.4 Effects of Pre-loading on UCS

The pre-loading effects on the strength of the EPS-sand geomaterial for the different stresses are displayed in Figure 9. It is observed that as the pre-loading stress increases the UCS also increased. The compactness of the specimens was found to increase under the increasing stresses such that the densities were also found to increase. Pre-loading stresses of 200kPa, 400kPa and 600kPa were initiated in this study.

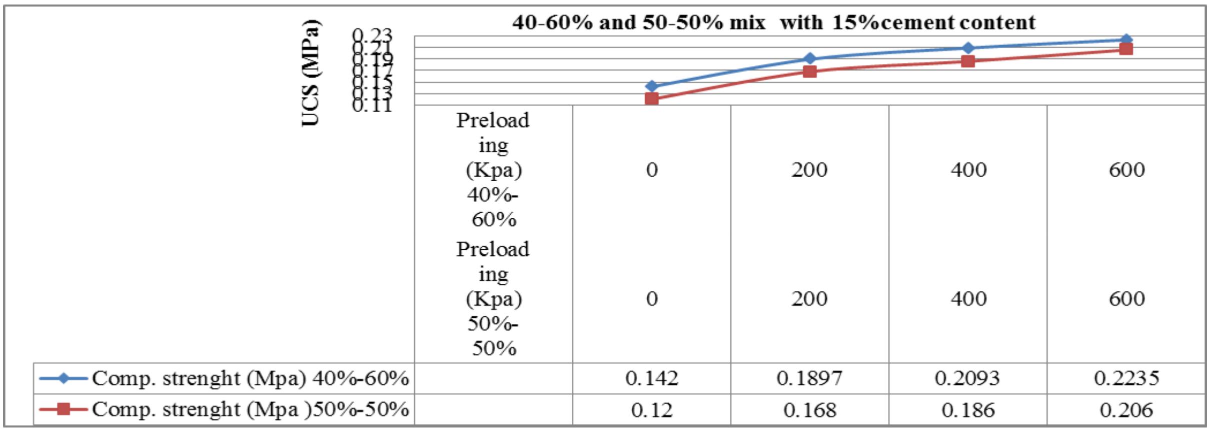
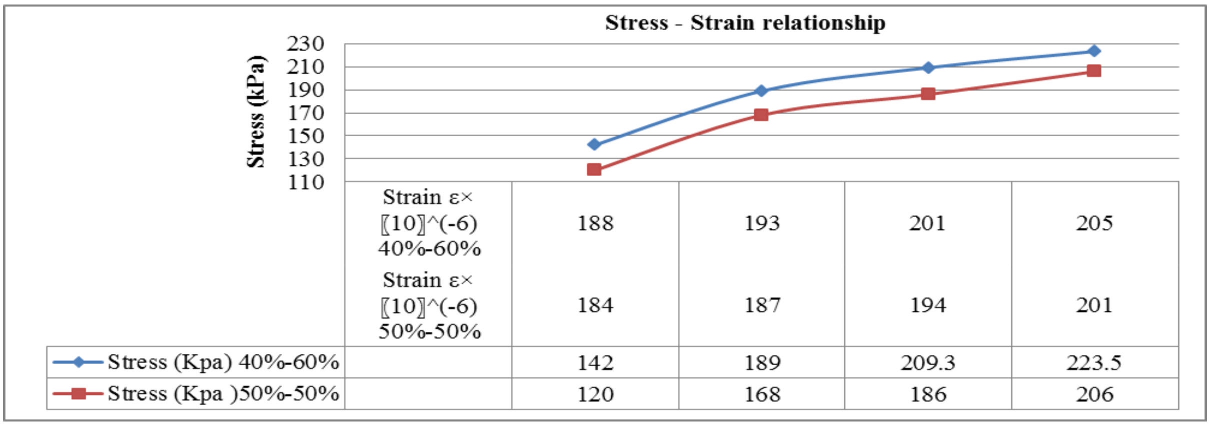


Fig. 9: Pre-loading effects on UCS

Reductions in the heights of the specimens were observed to increase under increased pre-loading effects. The highest UCS values for both mix ratios were achieved under a pre-loading stresses of 600MPa. UCS values of 0.2235MPa and 0.206MPa for 40-60% and 50-50% ratios were achieved under pre-loading stresses of for 600MPa respectively.

3.5 Stress-strain behavior of EPS-sand specimens

The behavioral pattern of the tested specimens shows a direct correlation between the stresses and strains (calculated from the modulus of elasticity) of the specimens from both mixes. It is clearly revealed in Figure 10 that the strain on the samples increased with increasing applied stresses.



Strain ε× [10]^(-6) 40%-60%	188	193	201	205
Strain ε× [10]^(-6) 50%-50%	184	187	194	201
Stress (Kpa) 40%-60%	142	189	209.3	223.5
Stress (Kpa)50%-50%	120	168	186	206

Fig. 10: Stress-strain relationship

The 40-6% ratios were found to have the highest strain values as compared to the 50-50% mix ratios. Hence, for a stress value of 223.5MPa a corresponding strain value of 205MPa was achieved for the 40-60% mix while a 206MPa stress created a strain of 201MPa for a mix ratio of 50-50% over the 7days curing period.

Comparison of respective sample mix ratios

Comparisons made between the 40%-60 % and 50%-50 % mix ratios showed their densities ranged from 1400kg/m^3-1430kg/m^3 for the 600kPa pre-load samples but for the 0kPa (non pre-loaded control samples) the density was between ranges of 1200kg/m^3-1300kg/m^3. The 600kPa stresses had the highest effects on both the 40-60 % and 50-50% mixes. Furthermore, the elastic modulus for the 40-60% ratios was still higher as compared to the 50-50% ratios across the various stresses of 600kPa, 400kPa, 200kPa and 0kPa. Therefore from this study, the bench mark for durable lightweight geomaterial mix ratios is a mixture of 40-60% under a stress effect of 600kPa which can be applied in single and double leave masonry wall but is however noted that the load carrying light weight geomaterial is directly proportional to the pre-loading stress applied to the geo-product.

IV. CONCLUSION

Laboratory tests were conducted on the formation of lightweight material by blending sand with EPS and cement. The effects of pre-loading compositions of EPS-sand, cement-sand and water-sand ratios on strength and densities of lightweight geomaterial were investigated and the following conclusions were reached;

- The UCS of light weight geomaterial is affected by the mix proportion and the cement content.
- Curing effect on the specimen was very significant even for a short curing age of 7days.
- Lightweight material can be produced from a mixture of CPS having a density in the ranges of 1750kg/m^3-2150 kg/m^3.
- 15%cement content increased the UCS of the mix due to cement hydration effect.
- The density and UCS properties of the geomaterial mix are made flexible by adjusting the CPS material constituent ratios.

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