



Research Article

Banjo A. Akinyemi*, John Ojediran, Olamide Olawale, and Stephen Ayanwola

Efficacy of expanded polystyrene as fine aggregate in cement mortars modified with latex paint as an alternative to polymer admixture

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Abstract: In this present study, the effectiveness of expanded polystyrene (EPS) waste used as 20, 40 and 60% fine sand replacement in development of lightweight cement composite was evaluated. The cement mortar was strengthened by 10% low cost latex paint emulsion as an alternative to the more expensive polymer admixtures. Six different mix designs were produced and tested for compressive and split tensile strength according to BS EN standards. Scanning electron microscope (SEM) analysis was also conducted to analysis the micrograph of the samples. It was observed that as the EPS content, latex paint polymer admixture and curing days were increased, marginal increment in compressive strength was obtained. However, EPS fines were most effective in improving the split strength while latex paint admixture had comparatively less part to play in the strength development. The micrograph images showed that the EPS fines were uniformly distributed within the microstructure and the latex paint developed polymer films. These mechanisms coupled with the cement hydrate products were responsible for the enhanced strength observed in the samples.

Keywords: EPS; latex; paint; polymer; cement; strength; modification

1 Introduction

Expanded polystyrene (EPS) material is majorly used in various industrial applications all over the world for insulation and packaging of industrial and domestic products [1]. However, huge stockpiles of EPS are left on dumpsites thereby harming the environment. Therefore it is expedient that they are reused and one method of doing this is through the full or partial replacement of natural gravel used for production of lightweight concrete [2, 3]. Nevertheless, it has been reported that lightweight concrete containing EPS aggregates suffers segregation during mixing based on their light densities [4]. In addition to this, they are hydrophobic in nature which results into poor bonding to cement mortars. Hence, the relevance of several studies conducted on enhancing the properties and reducing the segregation problem through addition of bonding additives [5], use of chemicals to treat the EPS beads [6] and the use of silica fume and superplasticizers to improve bonding and workability between EPS and concrete [7, 8]. Some studies considered the use of styrene butadiene rubber polymer (SBR) emulsions to enhance and modify the concrete in order to improve the properties [9]. It has however been noticed that polymer based admixtures such as SBR are expensive most times for a lot of applications and could not be afforded by some people. Polymer based admixtures are utilised in concrete to increase bond between cement and aggregates as well as improve flow and workability properties of the cement-based material [10]. Nonetheless, these suggested solutions may not be easily accessible around the world most especially in low-income developing nations. The best alternative that could be found easily within these regions is latex paint which studies have found to be a cheap [11] and good substitute for polymer admixtures used in cement applications [12, 13]. The major component of latex paint is polymers which account for over 50% solid content and it binds the pigments, extenders and other constituents of paints together. It also provides the ever-present film surfaces in the coating. Studies have shown that inclusion of latex paint as

*Corresponding Author: **Banjo A. Akinyemi:** Structures and Building Materials Unit Department of Agricultural and Biosystems Engineering, Landmark University Omuaran, Nigeria; Email: bantonbows@gmail.com

John Ojediran: Structures and Building Materials Unit Department of Agricultural and Biosystems Engineering, Landmark University Omuaran, Nigeria

Olamide Olawale: Department of Chemical Engineering, Landmark University Omuaran, Nigeria

Stephen Ayanwola: Department of Civil Engineering, Landmark University Omuaran, Nigeria

alternative to the more expensive polymer admixtures resulted into improved durability, rheology, toughness and strength of concrete applications [14–17]. These enhancements are caused by the presence of polymer resins in the paint which showed the same benefit as the conventional concrete polymer admixtures [18]. Based on existing literature, there is little available information on utilising latex paint as an alternative to polymer admixture in expanded polystyrene based concrete in order to provide a relatively affordable and low-cost lightweight structure. Hence, the relevance and the goal of this present study.

2 Materials and methods

2.1 Materials

EPS granular material with compositions shown in Table 1 was obtained from a discarded equipment shipping container. The EPS granules were subjected to heat in a ventilated oven at 150°C for 20 minutes to obtain denser granules which were subsequently milled to reduce into fine particles (average particle size of 0 – 4.5mm while particles retained on 2.0mm sieve was used) shown in Figure 1. The latex paint used as the alternative to polymer admixture was obtained from a building materials outlet with the seal intact. It has a density of 1325 kg/m³ and a solid content of

Table 1: Properties of EPS beads [21]

Properties	Value
Water absorption (%)	0
Average diameter (mm)	1.55
Max. particle diameter (mm)	2.30
Density (kg/m ³)	18
Collapse point (°C)	110 - 150
Melting point (°C)	160

53%. The result of a previous study has shown that 10% by cement mass is the optimum latex paint content needed for improved strength in cement mortars [19, 20]. Other materials used include Type 1 Portland cement with 42.5R grade with specific gravity of 3.12. The fine aggregate was well smoothed and has a specific gravity of 2.65, fineness modulus of 2.97 and absorption of 0.78. It was replaced with 20, 40 and 60% EPS fines by mass in order to develop a lightweight cement mortar with improved strength.

2.2 Mixture proportioning

The mix design was in accordance with ACI specification [22]. The composite was produced by dry manual mixing of fine sand, EPS fines and cement together first for about 3 minutes. Then 120 L/m³ and 92 L/m³ quantities of



Figure 1: Phases of EPS processing

Table 2: Mix proportion of composites

Content	X	W	C	V	A	T
Cement, g/cm ³	28.2	56.5	84.7	28.2	56.5	84.7
Fine sand, g/cm ³	84.6	169.5	254.1	84.6	169.5	254.1
EPS particles, g/cm ³	16.92	67.7	152.6	16.92	67.7	152.6
*Latex paint, g/cm ³	0	0	0	2.8	5.7	8.5
Water, g/cm ³	15.4	15.4	15.4	12.3	10.6	9.4
Water/cement ratio	0.54	0.27	0.18	0.44	0.19	0.11
Paint/cement ratio	-	-	-	0.1	0.1	0.1

*Latex paint used was 10% by mass of cement.

latex paint and water were added and thoroughly mixed together for another 3 minutes manually until an homogeneous slurry was formed. The experimental mix design is shown in Table 2. Cement: sand ratio of 1:3 was used based on the adopted standard.

2.3 Testing program

The slurry was placed in $50 \times 50 \times 50$ mm cubes for compressive strength tests which were conducted according to BS EN standard [23] using ELE ADR PRO 2000 compressive machine after water curing for 7, 14 and 28 days and dry curing for 24 hours. A total of 54 samples were produced and 5 specimens were tested for each variable at a constant loading rate of $0.1\text{N}/\text{mm}^2$ until failure occurred and the average recorded. Similarly, split tensile strength was performed using 50×150 mm cylindrical moulds in accordance with BS EN standard [24] after 7, 14 and 28 days curing in water and dry curing for 24 hours. Similar numbers of 54 samples were produced while 3 replicates were tested for each mix design at a loading rate of $1.2\text{kN}\cdot\text{secs}^{-1}$ using the same equipment and the mean were used to represent the results. Scanning electron microscope was also conducted using Jeol-7600F equipment. An acceleration voltage of 20 kV was used to observe the fractured surface of the specimens.

3 Results and discussions

3.1 Compressive strength

Progressive increase in compressive strength was obtained as the curing days and the EPS aggregates were increased (Figure 2). As the EPS replacement levels were increased, increase of 15 to 98% occurred in samples without latex paint additive. Similarly, on inclusion of latex paint additive to the mixture, improvements of 9 to 45% occurred in the compressive strength obtained from the samples. Using One way ANOVA, the influence of latex paint additive on the EPS cement mortars showed non-significant difference at $p < 0.06$, this meant that the addition of the latex paint as admixture had no obvious effect on the compressive strength of composite cements mortars. However, the peak performance for cement mortar samples without latex admixture was 23.3MPa while the inclusion of latex admixture resulted into a peak compressive strength performance of 24.6MPa which translates to a marginal significant improvement of 6%. This slight enhanced strength

is caused by comprehensive formation of cement hydration products during the wet curing period coupled with the film development from the latex paint additive during the dry curing phase. These two mechanisms were responsible for proper adhesion at the interfacial zone between the EPS-cement matrixes, hence the strength enhancement [7, 9]. It is remarkable to note that dry curing has possibly a negligible effect on the compressive strength of latex paint modified EPS-concrete because of effective retention of water by the polymer concrete. This could be possible because cement particles are fully enclosed by the polymers in the latex paint additive thereby trapping most water molecules nearby and maintaining improved cement hydration leading to the better compressive strength [18, 21]. The EPS samples under the compressive loading exhibited a gradual and more compressible failure mode which could not be likened to the conventional brittle failure pattern known for aggregates in conventional concrete. The tested samples were able to retain the load after it has failed without being fully disintegrated which showed that the composites possess high energy absorption capacity [7]. It is proposed that based on the outcome of the compressive strength results that the composite material cannot be used for load bearing structures such as beams and columns. However, they could be used for indoor applications such as panel walls, ceiling and flooring, wall plasters, bricks and concrete briquette because their total weight will be reduced [25]. The error bars on the chart represents ± 1 standard deviation of the results, these showed closed margins indicating the closeness of the individual values from the replicates tested to each other.

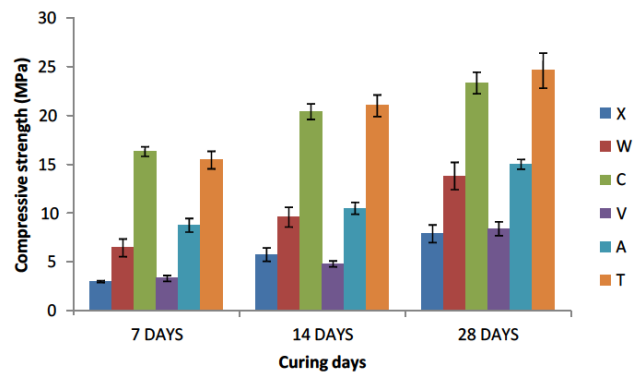


Figure 2: Compressive strength of samples

3.2 Split tensile

The split tensile (Figure 3) showed more improved split strength when the sand aggregates were replaced with EPS grains only compared with when latex paints were included into the matrix. As the EPS grains were increased, the split strength improvement after 7 days ranged from 16 to 101%, 29 to 93% increase after 14 days and 16 and 31% increment after 28 days for samples with EPS aggregates only. However, it was observed that on addition of latex paint additive, the split resistance strength reduced across the samples tested when compared with specimens with EPS granules alone. After 7 days, samples V, A and T had 40, 34 and 119% decrease in strength in comparison with specimens X, W and C respectively. Similar pattern of reduction in split strength were recorded for other curing days across the tested composite samples. The influence of wet curing on the film development of the latex paint by the solidification and dehydration process could possibly have reduced the tensile and bonding traits of the latex additive, hence the observed low performance of some samples [26]. This result is in line with the findings of Alemifer *et al.* [27] who suggested that there is possibly a maximum content of polymer latexes that could be used as concrete admixture beyond this point the strength is negatively affected. Although, a different view was presented by Assad [28] who reported an increase in split tensile strength due to the inclusion of latex polymers which supplied the needed and improved elasticity through development of strengthened tensile strength films which acted as the bridge between the micro-cracks in the cured cement concrete. However, in this present study, the presence of latex paint additive could have decreased the adhesive component located within the elastic region and subsequently resulting into increased interfacial shear stresses between the EPS grains and the cement mortar. The findings of Juan [29] has shown that air drying most times affect split tensile results because loss of moisture occurs within the core of the concrete at a slow pace which will lead to formation of tensile stresses at the exterior layer. This stress balances the compressive stress located at the still wet interior layer and provided water saturation does not take place, more moisture will be taken from mortars enclosing other aggregates leading to tensile shrinkage stress. Subsequently, the wet-cured specimens' resistance to external tensile loading will be reduced because of the drying lightweight cement composites. The report of an experimental study conducted by Akinyemi and Omoniyi [30] on the effect of polymer admixtures on natural fibre concrete showed that there is enhanced resistance to moisture penetration due to the enhanced mortar matrix due to the pres-

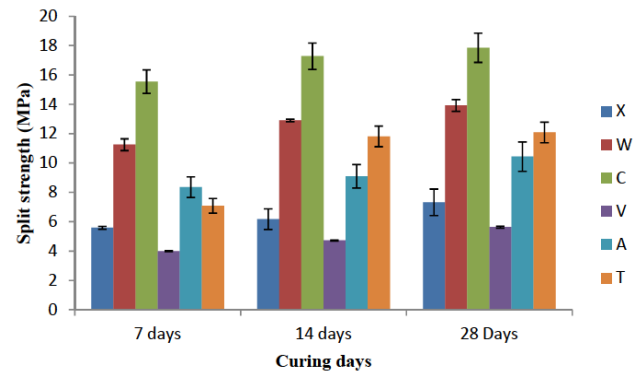


Figure 3: Split strength of samples

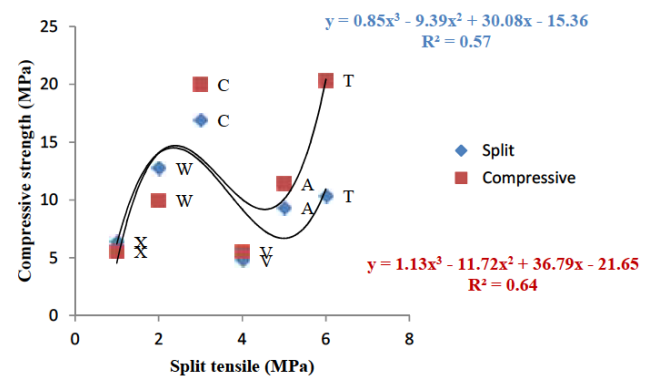


Figure 4: Correlation between compressive and split tensile strengths

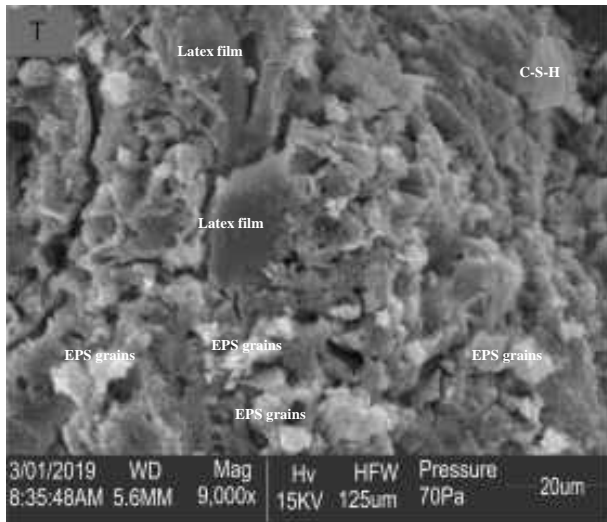
ence of polymer films in the internal network arrangement of the composite. The error bars on the chart represents ± 1 standard deviation of the results, these imply that the individual results from each of the tested replicates are relatively close and therefore the results is a good representative of the performance of the specimen under the conducted test. The correlation between compressive strength and split tensile strength is shown in Figure 4. It could be seen that as the compressive strength is on the increase, the splitting strength also was increasing a similar trend reported by Babu *et al.* [31]. In equations 1 and 2, Y is the compressive strength (MPa) and X is the split tensile strength (MPa). R^2 values of 0.57 and 0.64 were obtained depicting positive correlations.

$$y = 0.85x^3 - 9.39x^2 + 30.08x - 15.36, \quad R^2 = 0.57 \quad (1)$$

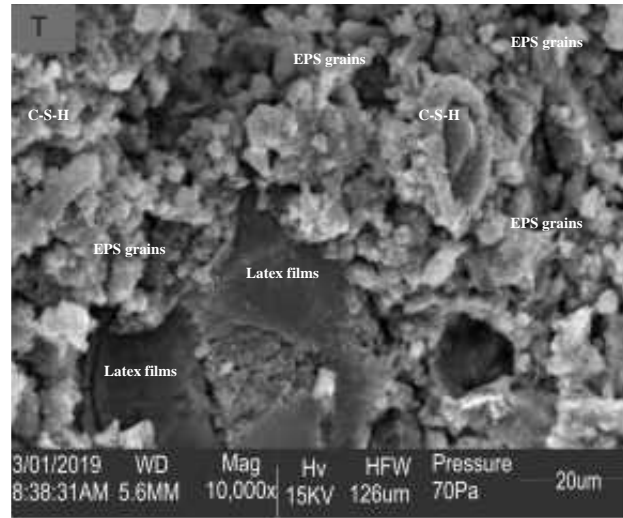
$$y = 1.13x^3 - 11.72x^2 + 36.79x - 21.65, \quad R^2 = 0.64 \quad (2)$$

3.3 Scanning electron microscope (SEM)

The micrograph in Figure 5(i; ii) show homogenous microstructural distribution of the EPS grains which with



(i) 9000x



(ii) 10000x

Figure 5: Micrograph of composite sample

dense surface which was responsible for the improved compressive strength observed with the samples. The SEM image in Figure 5(i) is at a magnification of 9000 \times ; it showed the existence of calcium silicate hydrate, polymer films formed by the latex paint and evenly dispersed fine EPS grains. The presence of lamellar structure of latex polymer film is evident and it is as a result of deposition of polymers on the cement mortars and EPS fines [32]. However, Figure 5(ii) at a magnification of 10000 \times clearly showed that the latex polymer film was continuous and bridged the pores and microcracks developed. This is responsible for the improved bond at the interface of the EPS-cement grains accompanied with the cement hydrate products leading to better mechanical performance of the developed composites.

4 Conclusion

Based on environmental concerns from dumping of EPS wastes on landfills, the reuse of these wastes as reinforcement in cement mortar is beneficial to develop lightweight cement applications. According to literature, this has however been extensively covered with some studies incorporating chemical admixtures into the matrix. It is noteworthy to report that the use of latex surface paint as an alternative to the more expensive polymer admixture is nonetheless novel. Based on the findings of this study, the replacement of fine sand with EPS grains led to significant improvement in compressive strength. This improvement

was however heightened as the latex paint was added with better enhancement observed in the strength development. This is possibly caused by the enhanced bonding at the interface among the latex paint polymer films, cement hydration products and the EPS granules. Split strength showed similar improvement on inclusion of EPS fines only, however the addition of latex paint in some of the specimens caused reduction in the results. This could be as a reason of the wet curing used as previous studies has shown that wet curing sometimes hamper strength development in polymer concrete hence the necessary crack bridging by the aggregates could not be achieved. It is suggested that the samples could be used for indoor applications requiring less loading applications.

Conflict of Interests: The authors declare no conflict of interest regarding the publication of this paper.

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