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INVESTIGATION OF THE UTILIZATION OF POLYVINYL ALCOHOL AS SURFACE TREATMENT IN MORTARS USING END-OF-LIFE TIRE

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Abstract

This study explores the potential benefits of employing polyvinyl alcohol (PVA) as a surface treatment in mortars incorporating end-of-life tire (ELT) particles. The investigation focuses on assessing the mechanical, physical, and thermal properties of cementitious mortars with the incorporation of PVA and ELT materials. The research aims to enhance the sustainability and performance of mortars by using waste materials and innovative surface treatments. The mechanical properties of the mortars were evaluated through compressive strength, flexural strength, and tensile strength tests. The addition of ELT particles with PVA exhibited notable effects on the strength characteristics of the mortars. The physical properties, including porosity, unit weight, and water absorption, were examined to understand the material's structural integrity and durability. The study also delved into the thermal behavior of the mortars using techniques such as thermal conductivity analysis. Results indicate that the incorporation of PVA as a surface treatment contributes to improved mechanical strength, reduced porosity, and enhanced durability of the mortars. The synergy between PVA and ELT particles demonstrates promising outcomes in terms of sustainable construction materials. The study provides insights into the potential of utilizing waste materials for enhancing the performance of mortars, contributing to both environmental conservation and construction industry sustainability.

Keywords: *ELT, PVA, Silica Fume, Surface treatment, Sustainability*

1. Introduction

In today's construction sector, sand, a fundamental component of cement mortars, is becoming a diminishing resource. The escalating demand, environmental concerns, and the unsustainable nature of sand extraction processes all indicate that this valuable natural resource is depleting. The decreasing availability of sand poses a significant challenge to the construction industry, as the unique properties of sand are crucial for the durability and strength of cement mortars. This situation necessitates the exploration of alternative materials and methods. Innovative and sustainable solutions would be a crucial step towards researching materials that can replace sand in the production of cement mortars while simultaneously reducing environmental impacts. In this context, focusing on new sources such as industrial waste, recycled materials, or eco-friendly alternatives could help lay the foundation for a sustainable future for cement mortars. In this respect research on the use of waste materials such as end-of-life tires (ELT) and fly ash in civil engineering continue.

The increasing number of vehicles worldwide directly impacts the amount of waste generated. Approximately 1.5 billion ELTs are generated each year, and it is estimated that this number will reach 5 billion annually by the year 2030 [1]. Due to the durability of tires in various weather conditions and their resistance to biological decomposition, their natural degradation is a time-consuming process. Incineration is the most widespread method for disposing of waste tires as it is the easiest and most cost-effective way to eliminate them. However, burning waste tires can pose fire hazards and produce detrimental compounds that threaten the health of living organisms. Additionally, the residual dust after combustion can lead to significant environmental pollution by contaminating the soil.

The utilization of ELTs in concrete production is an environmentally friendly method due to its ability to enhance low permeability, increase acoustic damping, and reduce thermal conductivity. This approach can contribute to improved building energy efficiency and noise reduction. Additionally, the use of ELTs in concrete offers advantages such as low density, acid resistance, freeze-thaw resistance, chloride permeability resistance, increased damping capacity, flexural impact strength, and toughness. These benefits make applications like recycled rubberized concrete, lightweight concrete, noise barriers, pavements, reinforced columns for earthquake-resistant structures, and rubberized concrete beams with high impact resistance highly practical. However, the incorporation of waste tires in concrete can lead to a significant loss of strength due to the weak adhesion between cement and rubber.

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Gheni et al. (2017) investigated the cement-waste tire interface region using Scanning Electron Microscopy (SEM) analysis. They observed that the bond between tire particles and the cement paste was weaker than that with natural aggregates, which was identified as the cause of the systematic decrease in compressive strength of the samples. The key to enhancing the strength of concrete incorporating waste tires lies in improving the interfacial strength between waste tire particles and the cement paste. Some researchers have suggested chemically modifying the waste tire/cement interface to enhance the bonding performance between rubber particles and the cement paste [2].

Guo et al. (2017) employed two different surface treatment methods (NaOH and Silane Coupling Agent) and three coating techniques (cement, silica fume+cement, cement+Na_2SiO_3) to enhance the rubber-cement adhesion. In general, methods treated with NaOH demonstrated the potential to improve the mechanical performance and enhance the long-term durability of rubberized concrete. Samples with waste tire aggregates treated with NaOH solution exhibited a decrease in thermal conductivity and compressive strength by 15.5% and 3.81%, respectively, compared to the control samples [3]. Kashani et al. (2018) utilized five different surface treatment methods (cement coating, silica fume coating, NaOH, potassium permanganate, and sulfuric acid immersion) to mitigate the strength loss in concrete incorporating waste tires. The results showed a compressive strength increase ranging from 27% to 56% compared to the control concrete containing 10% waste tires, with the most significant improvement observed in sulfuric acid immersion and silica fume coating [4].

Thong et al. (2016) indicated that the use of PVA contributes to improved adhesion between cement mortar and aggregates by reducing the formation of calcium hydroxide ($Ca(OH)_2$). According to this study, PVA can be employed as a surface pre-treatment for aggregates in cement-based composite materials [5]. Ho et al. (2018) utilized PVA-treated recycled concrete aggregate to replace 25% of the natural fine aggregate in concrete. It was noted that PVA coating enhanced the workability of the resulting fresh concrete and prevented water absorption by forming a polymer thin film on aggregate surfaces [6]. Han et al. (2020) proposed an innovative surface treatment method using PVA to address the insufficient adhesion issue and improve the hydrophilicity of waste tire rubber. The addition of a 0.1% PVA solution was shown to increase the 28-day compressive strength by 7% to 14% and the 28-day flexural strength by 20% to 38% [7].

In the present study, we aimed to the potential benefits of employing polyvinyl alcohol (PVA) and silica fume as a surface treatment in mortars incorporating ELTs. For this purpose, physical, mechanical and thermal properties of cement mortars were investagated.

2. Materials and Method

2.1. Materials

In the context of this research, we formulated 18 types of ETLs cement mortar employing cement, silica fume, CEN standard sand, ELTs. While the specific gravity of standard sand is 2.568, the specific gravity of ELT is 0.952. The gradation curve of the standard sand and ELT used is presented in Figure 1. The materials used in the study is shown in Figure 2.

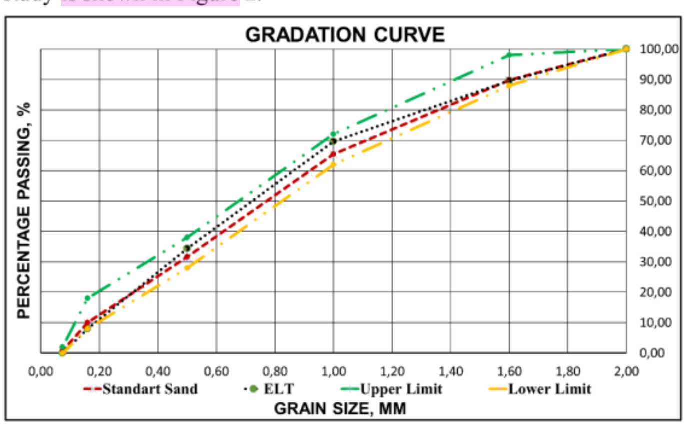

Figure 1. Gradation curve of ELT and standard sand.

450 grams of cement (CEM I 42.5 R), 225 grams of water and 1350 grams of standard sand were used in the production of the reference sample (C1). Table 1 lists the types of samples produced.

Polyvinyl alcohol is a notable example of polymer chemistry, commonly abbreviated as PVA. This polymer is produced through the polymerization of vinyl alcohol monomers and is a water-soluble polymer. PVA finds application in various industrial processes, particularly in adhesives, textile dyeing, food packaging, pharmaceutical manufacturing, and numerous other fields. Due to its water-resistant properties, adhesive strength, and film-forming capabilities, PVA is widely used [8]. PVA was utilized at the rate of 0.5% and 1% of the water used in mortar production. C2 mortar contains 0.5% PVA, C3 mortar contains 1% PVA.

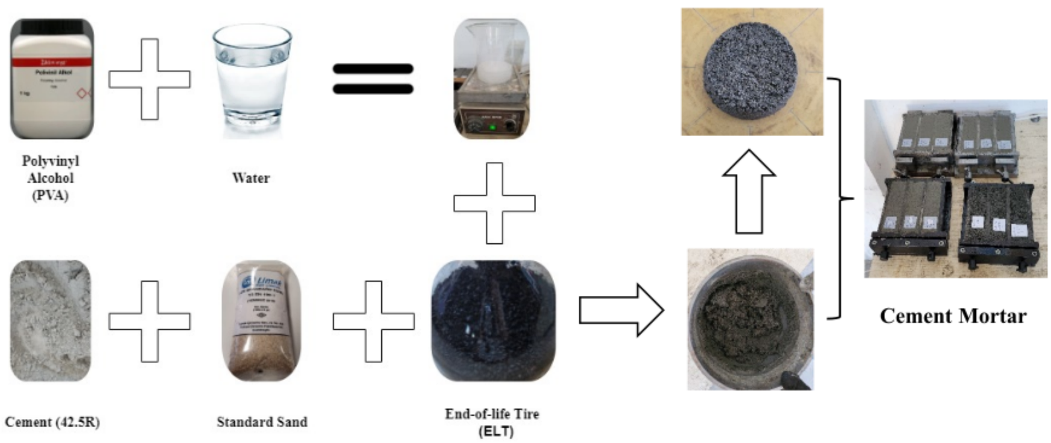

Figure 2. The framework of the study.

Table 1. Types of samples produced.

Sample Type	ELT / PVA (%)	Sand (g)	ELT (g)	PVA (g)
ELT-0	10%-0.0	1215	50.0	0.00
ELT-1	10%-0.5	1215	50.0	1.13
ELT-2	10%-1.0	1215	50.0	2.25
ELT-3	20%-0.0	1080	100.1	0.00
ELT-4	20%-0.5	1080	100.1	1.13
ELT-5	20%-1.0	1080	100.1	2.25
ELT-6	40%-0.0	810	200.1	0.00
ELT-7	40%-0.5	810	200.1	1.13
ELT-8	40%-1.0	810	200.1	2.25
ELT-9	60%-0.0	540	300.2	0.00
ELT-10	60%-0.5	540	300.2	1.13
ELT-11	60%-1.0	540	300.2	2.25
ELT-12	80%-0.0	270	400.3	0.00
ELT-13	80%-0.5	270	400.3	1.13
ELT-14	80%-1.0	270	400.3	2.25
ELT-15	100%-0.0	0	500.3	0.00
ELT-16	100%-0.5	0	500.3	1.13
ELT-17	100%-1.0	0	500.3	2.25

2.2. Method

this research, the flow test of fresh mortar was performed according to TS EN 1015-3 [9]. Test for strength were carried out according to TS EN 196-1 [10]. Moreover, the thermal conductivity of mortar was tested in using LINSEIS HFM 300/3 according to ASTM C 518 [11].

3. Results and Discussion

3.1. Physical properties

The workability of fresh mortar plays a pivotal role as it directly influences the properties of the hardened mortar [12]. The best results in terms of consistency in the mixtures created were obtained with the ELT-2 sample. The spread value of the reference sample was found to be 124 mm, the sample containing ELT-0 was 135 mm, and the sample containing ELT-15 was 101 mm. It has been found that ELT particles added instead of standard sand in fresh concrete reduce the slump value of the mortar and, accordingly, make the workability of the concrete difficult. This decrease in workability can be attributed to the increased water absorption in the ELT surface as a result of silica fume and PVA coating. Additionally, as the amount of ELT increased, the unit volume weight decreased. While the unit volume weight of the C1 sample is 2.20 g/cm^3, the unit volume weight of the ELT-17 sample is 1.20 g/cm^3.The flow table test and unit volume weight results are given in Fig. 3.

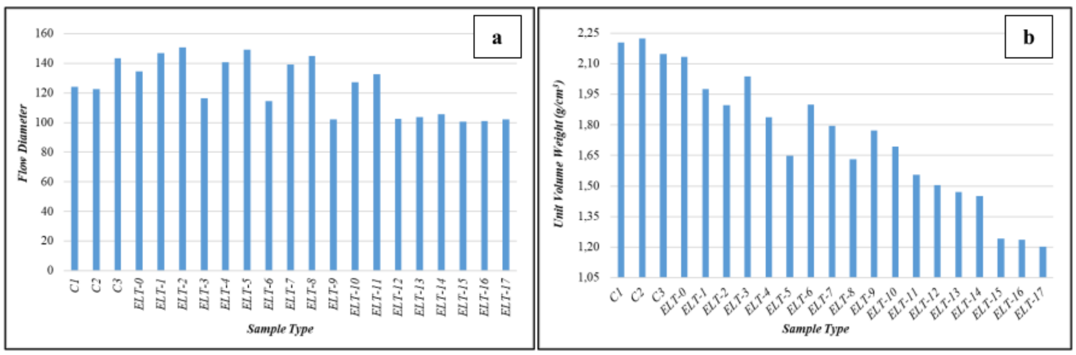

Figure 3. Results of flow table test (a) and unit volume weight (b) of mortars.

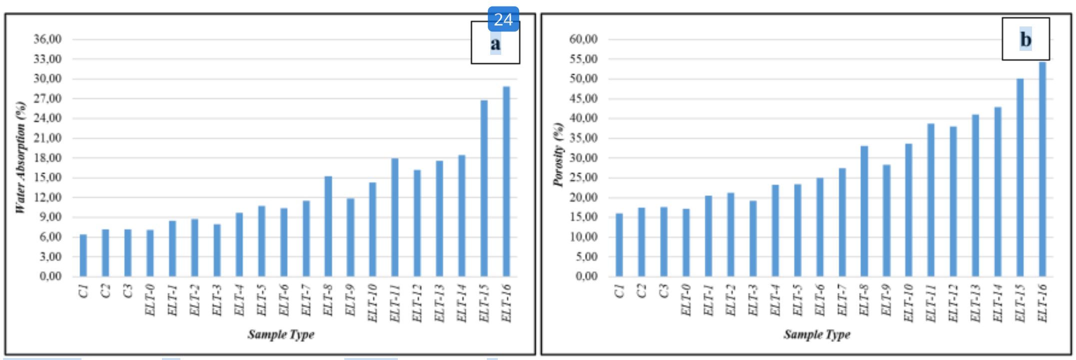

Figure 4. Results of water absorption (a) and porosity (b) of mortars.

3.2. Mechanical properties

Silica fume coating enhances compressive strength by approximately 15-50%, attributed to its high amorphous silica content and the promotion of calcium silicate hydrate (C–S–H) production through pozzolanic reactions. On the other hand, PVA coating increases the compressive strength by 3-36%. However, it did not have much effect on the tensile and bending strengths of both coatings. The results of strength tests are presented in Fig. 5,6.

3.3. Thermal properties

It has been observed that the thermal conductivity value decreases by 12-80% with the addition of waste tires. The thermal conductivity of sample C1 is 1.128 W/mK, ELT-2 is 0.900 W/mK, and EL-17 is 0.240 W/mK. It was determined that as the PVA ratio increased, there was a decrease in thermal conductivity. It is thought that the reason for this situation may be the increase in the vacancy rate. The results of thermal conductivty are presented in Fig.7.

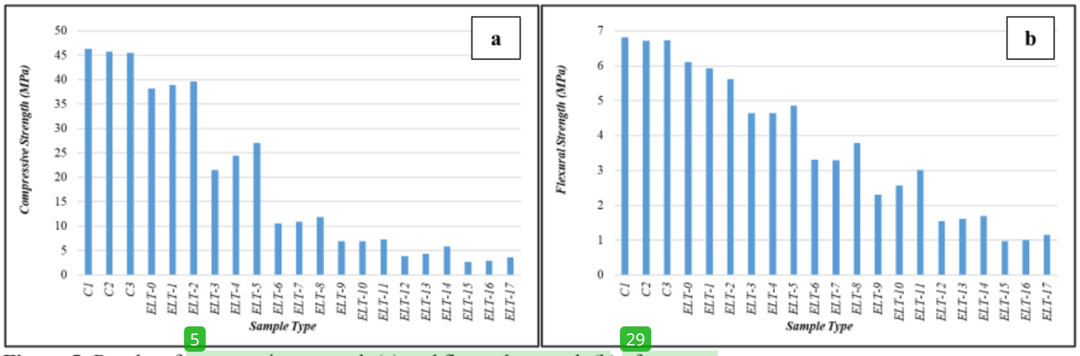

Figure 5. Results of compressive strength (a) and flexural strength (b) of mortars.

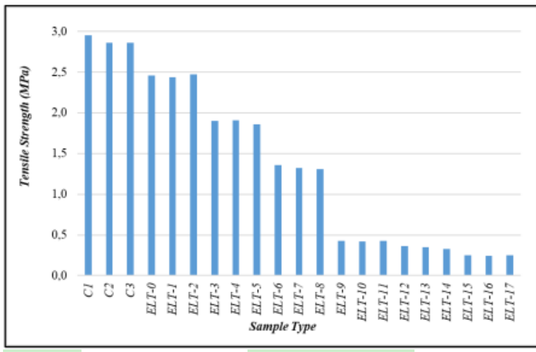

Figure 6. Results of tensile strength of mortars.

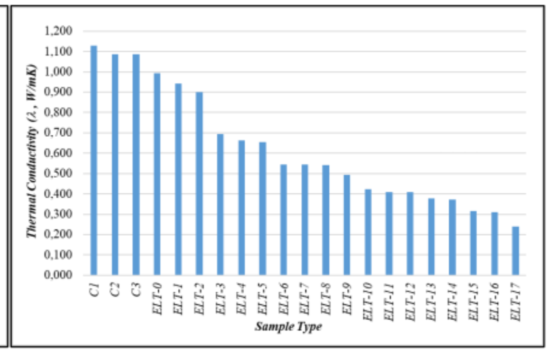

Figure 7. Results of thermal conductivity of mortars.

4. Conclusion

PVA and silica fume have used as promising agents in addressing the adhesion challenges associated with waste tire applications in various concrete formulations. PVA, a water-soluble polymer, and silica fume, a byproduct of industry, have been utilized for surface treatments to enhance the bond between waste tire particles and the cement matrix. The goal is to overcome the inherent adhesion problems that may compromise the structural integrity of rubberized concrete. Among these treatments, silica fume has demonstrated superior effectiveness in improving the adhesive strength between waste tire components and the cement matrix. Silica fume's fine particle size and pozzolanic properties contribute to a more robust interface, resulting in enhanced mechanical performance of the composite material. The utilization of silica fume in waste tire applications showcases its potential to be a key factor in optimizing the overall properties of rubberized concrete.

While silica fume has shown notable success, the application of PVA for addressing adhesion issues in waste tire recycling warrants further exploration. PVA's water-resistant properties, adhesive strength, and film-forming capabilities make it a promising candidate for surface treatment. However, additional research is needed to understand its full potential and optimize its usage in waste tire applications. This exploration could contribute to the development of new and enhanced strategies for effectively utilizing waste tires in the production of sustainable construction materials.

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